UNIVERSIDAD DE SANTIAGO DE COMPOSTELA

DEPARTAMENTO DE ECONOMÍA CUANTITATIVA

UNA METODOLOGÍA MULTICRITERIO PARA LA GESTIÓN SOSTENIBLE DE RECURSOS HÍDRICOS

Jacobo Feás Vázquez

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Tesis que presenta el licenciado D. JACOBO FEÁS VÁZQUEZ para obtener el grado de doctor en Economía, realizada en el Departamento de Economía Cuantitativa de la Universidad de Santiago de Compostela, bajo la dirección de los Profesores Dr.D. J. CARLOS DE MIGUEL DOMÍNGUEZ, catedrático del Departamento de Economía Cuantitativa de la Universidad de Santiago de Compostela y Dr.D. CARLO GIUPPONI, profesor asociado del Departamento de Ciencias Económicas de la Universidad Cà Foscari de Venecia

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A Totó y Carmucha

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1. LA GESTIÓN SOSTENIBLE DEL AGUA

1.1 INTRODUCCIÓN

Desde mediados del siglo XX, los países occidentales han empezado a tomar conciencia de las repercusiones que sus proyectos de desarrollo e industrialización tienen sobre el medio ambiente. El rápido crecimiento industrial había obviado, a principios de siglo, los efectos que podría producir sobre las generaciones venideras. El concepto de desarrollo sostenible comienza a tener mayor vigencia dentro del mundo económico.

En la actualidad la constatación de los efectos que el desarrollo económico ha producido sobre el medio ambiente ha propiciado un mayor interés y una mayor preocupación social en materia ambiental. Esta creciente preocupación ha llevado a los países más industrializados, y por tanto a los que más están contribuyendo a la degradación del medio ambiente, a tomar acciones con el objeto de mitigar, o al menos, suavizar, los efectos que el desarrollo económico produce a través de la implantación de mecanismos y herramientas de gestión medioambiental.

En la mayoría de los países desarrollados, el esfuerzo administrativo puede verse plasmado por medio de la elaboración de una gran cantidad de normativa en materia de medio ambiente y en el establecimiento de mecanismos de evaluación de impacto ambiental para aquellos proyectos cuya implantación se ha estimado que pudieran tener cierta relevancia sobre el medio.

Uno de los problemas que se plantea a la hora de analizar las repercusiones que dichos proyectos tienen sobre el entorno actual y futuro es precisamente la valoración de dichos efectos. Ciertamente resulta complicado establecer una estructura de precios sobre bienes para los cuales no existe un mercado en el que puedan interaccionar oferta y demanda. Más aún cuando en dicho precio deberíamos incorporar el efecto incierto que tendría sobre elementos futuros tales como las generaciones venideras.

En el presente capítulo se realiza una introducción al contexto decisional en el que se enmarca la gestión de los recursos hídricos en Europa. Para ello se parte de una análisis de la planificación de los recursos hídricos desde una perspectiva ambiental, destacando cuales son los elementos más importantes en dicho proceso, para a continuación abordarlo en el contexto en el que se desenvuelve en Italia como miembro de la Unión Europea y en el cual se presenta el estudio empírico del presente trabajo.

En el seno de la Unión Europea, todo el proceso de planificación y la gestión de los recursos hídricos están regulados por la Directiva Marco de Aguas (DMA) que debía de ser traspuesta a la legislación nacional antes de la finalización del año 2003. En un siguiente apartado se presentan los aspectos claves de la DMA y en que medida afectan al proceso de planificación de las políticas de gestión del agua.

Una vez analizado el marco administrativo de referencia para la planificación y gestión de los recursos hídricos, se hace una pequeña reflexión acerca de la importancia que cierto tipo de instrumentos tienen para la puesta en práctica de los objetivos establecidos a nivel europeo. Si bien, tal como propone la DMA, existen ciertos instrumentos de análisis como los métodos multicriterio, el análisis cote/beneficio o los precios hedónicos que facilitan los procesos de planificación, todos ellos poseen ventajas y desventajas a la hora de ser aplicados en el contexto de la gestión del agua. Pero de lo que no cabe duda, en cualquier caso, es de la importancia que los sistemas de ayuda a la decisión han tenido a la hora de facilitar la recogida, tratamiento y almacenamiento que este tipo de planificación requiere.

1.2 PLANIFICACIÓN, AMBIENTE Y RECURSOS HÍDRICOS

Las primeras referencias a la planificación de los recursos hídricos tienen su origen a principios de siglo XX, con la realización de análisis coste/beneficio dentro de una perspectiva que puede ser considerada como analítico racional.

El punto de partida de los análisis ambientales como establece Romero (1997) consiste en aceptar que la actividad económica trae consigo cambios en el ambiente que por lo general suelen ser dañinos.

Durante los últimos años, se han desarrollo métodos y criterios en materia económica para ayudar a la toma de decisiones en materia ambiental como es la utilización del Análisis Coste Beneficio. (valor actual neto de los flujos de caja descontados) para determinar la viabilidad económica del proceso de planificación.

Ciertos autores han criticado este método por dos motivos fundamentales. En primer lugar, autores como Paul R. Portney y John P. Weyant (1999) hacen referencia a los problemas de la elección de la tasa de descuento normalmente empleada, proponiendo como solución utilizar una tasa compuesta en función de la duración de los impactos ambientales. Hemos de tener en cuenta que el posible impacto ambiental de un proceso de planificación puede diferirse en cientos de años o incluso miles. Por otro lado, autores como Dixit y Pindyck (1995), Trigeorgis (1996) y Amram y Kulatilaka (1999) alegan que el método tradicional de los flujos de caja descontados relega a los decisores a una actitud pasiva y en la cual no se tiene en cuenta la incertidumbre que el futuro plantea, es decir, supone que vamos a seguir un plan predeterminado sin tener en cuenta como se desenvuelven los acontecimientos.

Este tipo de análisis limita la toma de decisiones al ejercicio de dos posibilidades: llevar a cabo el proyecto si su valor actual es positivo o no llevarlo a cabo en caso contrario. Pero no estamos teniendo en cuenta que a la hora de abordar un proyecto y de valorar sus posibles efectos, pueden existir caminos intermedios sin recurrir a los extremos.

En 1968 el “Club de Roma” reúne a la cúpula científica mundial para discutir las condiciones ambientales del planeta. En dicha reunión, los científicos advierten de las pésimas condiciones ambientales y su efecto sobre la calidad de vida en el planeta y hacen previsiones bastante negativas acerca del futuro, principalmente sobre los aspectos relacionados con la contaminación.

En las décadas de los 70 y 80, se produce el desarrollo de la mayoría de los métodos de gestión basados en criterios relacionados con el medioambiente natural. En los EE.UU. surge la exigencia de la realización de los estudios de impacto ambiental (EIA) que posteriormente fueron adoptados por el resto de los países más desarrollados – Canadá inicia en el 1973, Alemania en el 1975, Francia en 1976, Dinamarca en 1978-79 y Holanda en 1979-80 (Santos, 1995).

Todas las herramientas de gestión ambiental se basan en los principios comunes de planificación ambiental, es decir, ven en la planificación un proceso continuo que implica una serie de toma de decisiones o una evaluación de diversas formas alternativas de utilizar los recursos disponibles con el objetivo de alcanzar unas metas específicas en un determinado periodo de tiempo futuro (Conyers y Hills, 1984).

Las primeras referencias del uso de procesos de decisión estructurados y de modelos de ayuda a la toma de decisiones, aplicados a la planificación de recursos hídricos, bajo la perspectiva de la planificación ambiental data de la década de los años 30 (Santos, 1995). Sin embargo, hasta los años 60, los análisis de los impactos derivados de la acción antrópica eran principalmente entendidos bajo el enfoque técnico social y los métodos aplicados eran del tipo análisis coste/beneficio. Así, a inicios de los años 80, toman un gran impulso las investigaciones basadas en el uso de los métodos de análisis multicriterio que, entre otras ventajas, permiten englobar aspectos sociales, ecológicos y económicos bajo el mismo análisis.

Este tipo de métodos, según Goicoechea (1982), en relación a la investigación operativa como un enfoque científico para el proceso de toma de decisiones, la mayor parte de esta metodología multicriterio que plantea la existencia de objetivos múltiples tienen su origen en el trabajo del "*Harvard Water Program*" (Maas et al., 1962) y está basada en cuatro pasos dentro del proceso de planificación de los recursos hídricos, conforme con la filosofía analítica racional:

- Identificar los objetivos del sistema que se quiere planificar. Este paso supone la selección de los objetivos del proceso político;
- Transformar los objetivos en criterios. Esto implica el desarrollo de criterios detallados para reflejar los objetivos del sistema a planificar;
- Desarrollar el sistema usando los criterios anteriormente desarrollados, que reflejan los objetivos;
- Revisar los resultados del proceso del sistema planificado.

Esta teoría proporciona las bases para trasladar los objetivos de la sociedad al sistema que se pretende planificar, de una manera interactiva, usando las cuatro etapas de planificación. Ello implica la selección de objetivos, el desarrollo de soluciones viables de acuerdo con los objetivos y las restricciones impuestas al problema y la ordenación y selección final de la alternativa. El criterio de la maximización de los beneficios se convierte ahora en uno más de los criterios afrontados en la planificación multicriterio.

La planificación ambiental puede ser vista, de esta manera, como una formalización de un sistema básico de planificación, en la que los elementos que la forman pertenecen al medio natural y antrópico que están enmarcados en una determinada área geográfica.

La planificación ambiental, por lo general, parte de problemas complejos, lo que hace necesaria la utilización de un gran volumen de información. Por otro lado esta complejidad viene acentuada por el hecho de que se trata de un proceso en el que, por lo general, el poder de decisión reside en manos de varios decisores. Estas características hacen que sea necesario llevar a la práctica procesos de decisión de tipo estructurado en el que la sistematización de las respuestas se convierte en un aspecto clave. En este caso, los sistemas de ayuda a la decisión se hacen necesarios como herramientas metodológicas, porque tienen la capacidad de definir problemas, estructurar diagnósticos, analizar resultados, ordenar, solucionar y decidir sobre las alternativas (Hollick, 1981).

Supone además este tipo de planificación, una serie de etapas interrelacionadas entre si y que en ocasiones no son afrontadas o consideradas suficientemente en los actuales procesos decisionales. La Figura 1-1 representa, de forma esquemática, las etapas de un proceso de planificación ambiental. La falta de una planificación integrada o la adopción de una planificación parcial o de unos aspectos en concreto puede ocasionar graves problemas.

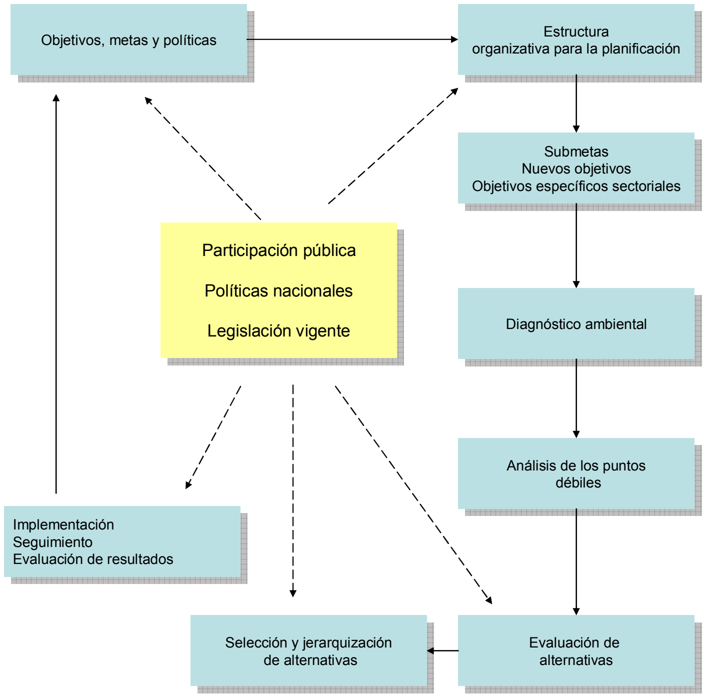

Figura 1-1 Etapas del proceso de planificación ambiental (adaptado de Santos, 1995)

En la citada figura se observa que la participación pública, las políticas nacionales y la legislación vigente son elementos que afectan a cada una de las etapa del proceso, y que pueden, en cada instante, decidir el rumbo de la planificación, interactuando mutuamente con el proceso decisional.

Cuando por ejemplo, la legislación vigente se vuelve obsoleta, impidiendo que exista una convergencia de alternativas, se puede iniciar un proceso para la actualización o modificación de la legislación. Es decir, de acuerdo con esta forma de pensar, la planificación ambiental es un proceso dinámico e integrado. Se puede observar además, que la planificación ambiental pasa por dos fases claramente diferenciadas: la primera de diagnóstico, normalmente elaborada a través de la espacialización de los datos ambientales, sociales y económicos del área estudiada y una segunda fase que comprende la evaluación de las alternativas propuestas en función del medio y que puede ser afrontada a través de la utilización de sistemas de ayuda a la decisión.

1.3 LA GESTIÓN DE LOS RECURSOS HÍDRICOS DESDE LA PERSPECTIVA DE LA DIRECTIVA MARCO DEL AGUA

1.3.1 La Política Europea del Agua

El enfoque de la Unión Europea (UE) en relación a la gestión de los recursos hídricos ha evolucionado desde el inicio de la década de los años 70, y ha culminado recientemente con la publicación de la Directiva Marco del Agua (DMA), Directiva (2000/60/EC), por la que se establece un marco comunitario de actuación en el ámbito de la política de aguas, de 22 de diciembre de 2000. Una serie de cinco Programas de Acción Ambiental, que comenzaron en el año 1973, han proporcionado el contexto y la base para las decisiones políticas que han definido la DMA y se han convertido en legislación europea en materia de aguas.

Existen diferentes aspectos y tendencias que han marcado el desarrollo de tales políticas y pueden ser considerados como una base de referencia importante para ser capaces de interpretar el enfoque actual que se persigue con la nueva Directiva. En primer lugar, hay que tener en cuenta la privatización del sector que se ha producido en varios países de la comunidad, lo que ha cambiado los sistemas de precios y las estructuras organizacionales para la gestión pública del abastecimiento de agua. En segundo lugar, la internacionalización de los mercados ha conducido a cambios de escala en algunas actividades económicas y consecuentemente a un incremento de la intensidad del uso del agua en algunos sectores: por ejemplo el crecimiento del turismo ha incrementado la demanda de agua para uso recreativo. En tercer lugar, un cambio que podríamos denominar ideológico, hacia un sistema de gestión basado en una mayor participación pública, lo que ha conducido a una revisión de los procesos políticos y en algunos casos a una redistribución de la autoridad entre las administraciones centrales, regionales y locales dentro de la estructura de gobiernos nacionales (Kaika, 2000). Estas tendencias han supuesto una demanda creciente y variada de recursos hídricos, y la aparición de nuevos agentes que ahora desempeñan un papel importante en la gestión de dichos recursos.

Los países miembros de la UE han afrontado de manera diversa los desafíos de esta nueva filosofía de gestión. Erik Mostert (1999) ha identificado dos modelos generales. En primer lugar el modelo de "autoridad" en el que la administración está basada en las cuencas hidrológicas y que poseen capacidad de financiación y poder de decisión independiente. En dicho caso, la gestión del agua puede ser considerada como un sector de política separado. El segundo modelo es el "modelo de comisión" en el que la gestión del agua es considerada en un contexto más amplio de gestión ambiental llevada a cabo por una determinada administración. En este caso se crean órganos de cuenca para resolver problemas derivados de la gestión transfronteriza (o en algunos casos donde sin existir una frontera política si existe una frontera administrativa) que surgen en la gestión estratégica de cuencas hidrológicas (Mostert, 1999). Cada una de estas estructuras favorece cierto tipo de enfoques y dificultan otros. El incremento del conocimiento y de las preocupaciones por el estado del ambiente y el descontento con los resultados de las políticas del agua y la utilización del suelo a nivel nacional y europeo han consolidado la posición de las organizaciones no gubernamentales (ONG).

Desde 1992 y firma de la Declaración de Río y de la Agenda 21, han tomado mayor importancia el aspecto de la participación pública y la implicación de los actores en el desarrollo de políticas y en los procesos de toma de decisiones. Existen todavía grandes carencias de formación y aspectos culturales que de un modo u otro dificultan los procesos de participación en la mayoría de las administraciones. El incremento del número de actores, tanto públicos como privados, subraya la necesidad de una mayor capacidad de colaboración para definir las técnicas de mediación y los enfoques cooperativos apropiados para una implicación activa de las partes interesadas. En la actualidad, sin embargo, este proceso se complica debido a la obligatoriedad de llevar a cabo procesos de planificación participativos.

1.3.2 Aspectos clave

Los primeros esfuerzos legislativos que se realizaron en materia de gestión de agua, establecieron como uno de los aspectos prioritarios la calidad de las mismas. Este enfoque está relacionado con las prioridades del primer Plan de Actuación Ambiental: preservar la salud pública; protección del ambiente; y harmonización de las reglas ambientales dentro de la UE. Aubin y Varone (2002 y 2004) identifican dos generaciones de directivas relacionadas con el agua, entre el 1972 y el 1995.

En el primer grupo de instrumentos, se dan los primeros pasos para alcanzar los objetivos ambientales. Para las aguas superficiales destinadas al consumo, aguas aptas para el baño y la pesca, se establece la definición de los estándares de calidad de acuerdo con los usos humanos y los requerimientos mínimos. Se prescriben además los métodos de monitorización y análisis, se describen las sustancias peligrosas, y los estándares de emisión se basan en la utilización de la “mejor tecnología disponible”.
En la segunda generación de directivas, se realiza un mayor esfuerzo en la mejora y la protección de la cualidad del agua en los territorios de la UE. Un seminario sobre la Política Comunitaria del Agua remarcaba que “la lucha contra la contaminación y las substancias peligrosas debería ser intensificada”, y como consecuencia de ello, en el

período desde 1991 hasta 1998, se desarrollan nuevas directivas en materia de aguas urbanas residuales, contaminación agrícola, y emisiones industriales, con especial atención en estándares de contaminación (Aubin y Varone, 2002 y 2004). En cualquier caso, este enfoque legislativo en materia de política de agua ha sido considerado como “fragmentado e inconsistente, con métodos diferentes, y en ocasiones definiciones y propósitos conflictivos” (Foster et al., 2000). Una implementación inconsistente dentro de la UE de varias de estas directivas ha dado lugar a este tipo de problemas.

Durante las tres décadas en las que se ha desarrollado la política de control de la contaminación y mejora de la calidad de agua en la UE, ha existido un gran debate sobre la forma más efectiva de controlar las causas de la contaminación, y en consecuencia alcanzar los requerimientos establecidos por la legislación europea.

Cuando se hace referencia a focos de contaminación, es posible aplicar el enfoque del Valor Límite de Emisión (ELV) que hace referencia a los valores estándar definidos para cada una de las substancias que se emiten. En los diferentes estados de la UE, en muchos casos existen estándares nacionales y se establecen cuotas de emisión. La mayor desventaja de este enfoque, que tiende a ser el más común, es la falta de flexibilidad de los estándares de emisión para ajustarse a los efectos que se producen en el medioambiente (Chave, 2001). De esta manera, aunque este método es de fácil implementación, los resultados pueden ser muy flexibles para alcanzar los objetivos ambientales o demasiado restrictivos para permitir el completo desarrollo de las actividades humanas. Más aún, cuando estamos ante un foco de contaminación difusa, como es el caso de muchas de las actividades agrícolas, el EVL tiene una aplicación limitada.

Otro enfoque es el conocido como Objetivo de la Calidad del Agua (WQO), y consiste en identificar los cursos de agua receptores en términos de su uso, de acuerdo con el grado de pureza requerido para dichos usos. El objetivo es alcanzar los estándares descritos para la calidad del agua, y los métodos de control pueden ser ampliados por medio de la imposición de mayores límites de emisión. Resulta obvio, que la monitorización requerida para este tipo de enfoque debe ser muy extensiva para poder analizar los resultados y considerar otros factores, a mayores de la emisión de contaminantes que pueden influenciar la calidad del agua, como las propiedades de autodepuración de las masas de agua o la cantidad de dilución posible.

Dentro de la UE, existen diferencias de enfoque dentro de los países miembros. Los Estados miembros están obligados a transponer las directivas europeas a la legislación nacional dentro de los plazos establecidos. Fallos en la adopción e implementación de la legislación europea es punible por la Corte de Justicia Europea, y se debe destacar que no es un caso aislado el que alguno de los estados vengan penalizados por los fallos en el cumplimiento de la legislación europea en materia de gestión de los recursos hídricos.

En algunos de los países, se afronta la resolución de problemas de manera independiente evidenciada por el gasto realizado en monitorización del estado de las cuencas hidrológicas, consulta pública, y una reestructuración de las instituciones para el desarrollo de prácticas de gestión del agua más sostenible. En otros países, es evidente que existe un enfoque menos proactivo y se siguen las pautas establecidas por la UE con cierto retraso, centrándose sobre todo en alcanzar los mínimos requisitos de la manera económica más eficiente. Este punto de vista puede variar de acuerdo con la importancia que suponga alcanzar los objetivos ambientales y el concepto de sostenibilidad, y el grado de divergencia entre las actuales prioridades en lo referente a las decisiones requeridas para los objetivos de la calidad del agua.

La DMA no es solo una respuesta a las condiciones de los recursos hídricos en Europa, sino que es también una respuesta a las características socio-económicas de la Comunidad Europea. Este nuevo ejemplo de legislación refleja el pensamiento contemporáneo en la evolución de la historia política europea. Proporciona las herramientas necesarias para perseguir los objetivos para mejorar y proteger la calidad de los recursos hídricos, que ahora están bien establecidos, adoptando los estándares y los procedimientos más apropiados para cada situación dada. Al mismo tiempo, los gobiernos nacionales están obligados a trabajar siguiendo las líneas guía que subrayan la integración de los procedimientos de planificación y comunicación, y que pueden suponer una reestructuración de las reglas institucionales.

El 6º Programa de Acción Medioambiental, que se inició a finales del 2002, se concentró más en el concepto de sostenibilidad, creando por lo tanto un contexto para el desarrollo e implementación de políticas que promoviesen y soportasen algunos de los aspectos más innovativos de la DMA.

1.3.3 La Directiva Marco del Agua de la EU

Esta nueva Directiva puede ser considerada como el documento legislativo más significativo en la legislación sobre aguas en Europa en los últimos veinte años” (Foster et al, 2000). Ha sido diseñada para resolver algunos de problemas más persistentes que impiden la consecución de los objetivos ambientales europeos, y que puede ser interpretada como un intento de establecer una estructura legislativa coherente para la protección de medioambiente hídrico en el contexto de alcanzar un desarrollo sostenible.

Representa además un paso crucial para asegurar una estructura efectiva para la aplicación de las directivas existentes que regulan el agua en Europa. De hecho, ocho de esas directivas serán revocadas en dos fases en los próximos treinta años, quedando la DMA como un instrumento legislativo de base. Otro de los aspectos fundamentales de esta nueva Directiva es que se establece un enfoque combinado que permite tanto el uso de WQO como de ELV que establece un camino a través del que se dirige la fragmentación de la política europea en materia de agua.

Esta Directiva es el resultado de más de diez años de trabajo, llevando más de cinco años su finalización desde que fue inicialmente propuesta. Está compuesta de más de setenta páginas y está articulada en veintiséis artículos y once anexo. El enfoque integrado que adopta puede relacionarse con cuatro disciplinas, y esto ayuda a ilustrar la importancia de la propuesta, su propósito y la cantidad de trabajo necesario que supone alcanzar los objetivos que se establecen.

Aspectos Territoriales

Los artículos 3, 5, 11 y 13 de la DMA reorientan el objetivo geográfico de la gestión del agua. Es decir, dirigen las acciones en función de los límites existentes, que pueden estar definidos por las fronteras entre dos países, dos regiones o dos municipios, o por áreas dividas en función de la actividad desarrollada, se define una nueva interpretación del territorio europeo en función de los sistemas hidrológicos. Se requiere a los Estados miembros que describan su territorio nacional en términos de cuencas hidrográficas individuales y asignándolas a las demarcaciones hidrográficas que permiten la puesta en marcha de la DMA. Las pequeñas cuencas hidrográficas y las aguas costeras pueden ser asignadas ambas a las demarcaciones más próximas.

De esta manera se definen las nuevas unidades de gestión que serán la base para la planificación, seguimiento, comunicación, y la organización de las instituciones responsables de la protección del agua. Este enfoque prevé por tanto la formación de demarcaciones hidrográficas internacionales que tradicionalmente vienen divididas por las fronteras nacionales. La Comisión Europea facilitará la definición de las cuencas internacionales y la asignación de responsabilidades a requerimiento de los Estados miembros involucrados.

Muchas de los aspectos geográficos y de las actividades humanas dentro de estas cuencas tienen una influencia sobre la calidad y la cantidad de agua de los ríos que es de sobra conocida. La mayoría de los países tienen información de estas interacciones en las cuencas de los ríos y normalmente se las decisiones están basadas en los requerimientos a nivel de cuenca. La DMA consolida este enfoque y lo extiende a todas las cuencas incluyendo las aguas subterráneas, estuarios y aguas costeras de una manera más comprensiva (Chave 2001). Esta redefinición de la gestión del territorio de los Estados miembros es un importante prerrequisito para una serie de obligaciones que son de naturaleza política.

Esta nueva división geográfica será la base para la asignación de los derechos y las responsabilidades asociadas a la gestión del agua. Los Estados miembros están obligados a nombrar una autoridad competente para cada uno de las demarcaciones hidrográficas que será el responsable de llevar a cabo las actividades de gestión de acuerdo con la DMA. En algunos países las estructuras institucionales existentes se podrán orientar hacia esta nueva concepción territorial sin causar demasiados problemas mientras que en otros países, las estructuras institucionales deberán ser modificadas de manera significativa.

La tarea fundamental de las autoridades competentes será el desarrollo del instrumento fundamental para la gestión de cuencas, es decir el Plan Hidrológico de Cuenca(PHN). Estos planes deben establecidos en base a la información que será recogida en una informe comprensible con el objeto de de determinar el status actual de las cuencas examinando las características físicas y geográficas; las actividades industriales; los asentamientos de población y sus actividades en la cuenca; una revisión del impacto en el medioambiente de las actividades humanas; y un análisis económico del uso del agua (Chave, 2001). El objetivo general del PHC es definir la forma de alcanzar un "buen estado ecológico" de las masas de agua a través de la puesta en marcha de un programa de medidas. La definición de los objetivos ambientales debe ser descrita en términos de calidad ecológica y química de las aguas superficiales y en términos de cantidad y propiedades químicas de las aguas subterráneas, con referencia a su situación actual y a los parámetros propuestos en la DMA. La situación óptima para cada uno de los sistemas individuales dependerá también del tipo y de su localización geográfica dentro de Europa.

Aspectos Ecológicos

Mientras que la calidad del agua ha sido uno de los objetivos principales claramente identificados por la política europea de aguas en los últimos treinta años, la DMA introduce un enfoque más holístico para analizar el estado de los recursos hídricos, considerados como parte de un sistema ecológico más amplio. Este punto viene reflejado en la definición de Estado Ecológico que se da en el Anexo V de la DMA y que incluye criterios biológicos, hidromorfológicos y elementos físico-químicos de la calidad del agua.

El artículo 4 insta a los Estados miembros a desarrollar los programas de medidas que se especifica en los Planes Hidrológicos de Cuenca operativos con objeto de alcanzar los objetivos ambientales que han sido establecidos de manera individual para cada uno de los tipos de masas de agua. Este artículo proporciona la definición de los adjetivos de “artificial” o “altamente modificados” para las masas de agua que servirán de guía para alcanzar los objetivos ambientales centrados en el concepto de “potencial ecológico”. En algunos casos usar la calidad natural como punto de referencia no es necesariamente realístico en una situación en la que las actividades humanas han determinado la situación existente y las características de los cursos de agua.

Es interesante resaltar que a través de la nueva Directiva se ha producido un cambio hacia una visión menos antropocéntrica. No solo se han rediseñado los límites geográficos reconociendo los fenómenos naturales, sino que el uso de técnicas de análisis biológico ha ido más allá estableciendo un enfoque de gestión que describe el papel de salvaguardia de las autoridades competentes. El requisito de la consideración del estado de una serie de elementos que interactúan en el sistema de cuenca es un paso más hacia un visión más holística para alcanzar los objetivos de calidad de agua, que en última instancia están relacionados con la protección de la salud humana.

Los procedimientos de análisis que utilizan índices biológicos como indicadores ecológicos comprensivos, son ampliamente utilizados en Europa y generalmente se basan en indicadores de especies o de diversidad de especies como una medida de la degradación de la calidad del agua de lo que debería ser considerada como calidad natural (Chave, 2001).

Los retos propuestos en la DMA en relación a la evaluación del estado ecológico y por tanto para la consecución de los objetivos ambientales pueden ser considerados como relevantes. Los Estados miembros deben analizar el estado de las cuatro categorías de masas de agua: ríos, lagos, aguas transitorias; y aguas costeras. Con objeto de alcanzar los requisitos mínimos de la DMA, se debe llevar a cabo un seguimiento para analizar este tipo de aguas en función de los parámetros establecidos para cada uno de los sistemas en función de una clasificación de alto, bueno, moderado pobre o mal estado. El criterio utilizado para esta clasificación se establece en el Anexo V. El hecho de que esta clasificación sirva para comparar las modificaciones de condiciones naturales, no se han establecido valores numéricos en la clasificación de los sistemas.

La posibilidad de que diferentes niveles de calidad ecológica sean clasificados dentro de la misma categoría es un problema que se debe resolver. Con un programa de análisis tan amplio que implica una aplicación por parte de los Estados miembros de una variedad de esquemas de clasificación, es la interpretación de los resultados la que guiará la interpretación de los resultados. La Comisión ha planificado un ejercicio de calibración que será aplicado a una serie de lugares que cubre cada una de las eco-regiones definidas en el Anexo XI con objeto de conseguir una mayor consistencia en la clasificación de las masas de agua. Un requisito previo para la realización de este ejercicio es la identificación de las zonas apropiadas que puedan ser incluidas en categorías más amplias, así como la medida de características específicas. Los Estados miembros deberán aplicar su propio análisis tanto a las zonas de ejemplo como a zonas similares en su propia área, y los resultados globales serán clasificados para uso general que han sido obtenidos a partir de valores numéricos obtenidos por medio de una serie de comparaciones.

Por un lado, los objetivos ambientales han sido articulados de una manera más holística y quizás más realista en esta nueva Directiva, guiando a los Estados miembros a considerar el agua como una parte del ecosistema en los procedimientos de análisis y desarrollando instrumentos de planificación y programas de medidas. Por otro lado, reconociendo la posibilidad de variación y diversidad en lo que es esencialmente el objetivo general de alcanzar un “buen estado ecológico”, la DMA está abierta, en algunos aspectos, a la interpretación lo que puede dar lugar a ciertos problemas de grado y fechas de cumplimiento.

Aspectos Económicos

Los aspectos económicos de la gestión del agua están estrechamente relacionados con la naturaleza de este recurso particular. Los sistemas vivos, incluida la sociedad humana tienen una gran dependencia del suministro de agua y por lo tanto el agua es considerada como un bien público, por lo que un sistema de gestión que podría ser aplicado a otro tipo de bienes no es completamente adecuado. La DMA resalta en el primer párrafo que el “agua no es un bien comercial como cualquier otro, mejor dicho, es una herencia que debe ser protegida, defendida y tratada como tal”.

El enfoque de ”*full cost recovery*” descrito en la DMA requiere que los Estados miembros cuantifiquen los costes asociados al uso de los recursos hídricos. Esto debe ser llevado a cabo para cada uno de las demarcaciones hidrológicas de manera previa al desarrollo de los Planes de Cuenca. Este requisito viene establecido en el artículo 5 y los detalles específicos vienen reflejados en el Anexo III. Esta es la primera vez que un instrumento legislativo a nivel europeo hace referencia a la necesidad de contabilizar los costes ambientales resultado del uso del agua (Chave, 2001).

La DMA establece también la necesidad de revisar el sistema de precios de tal manera que los costes de los servicios, los costes ambientales y los asociados con el daño causado a los ecosistemas acuáticos sean completamente recuperados, mientras que hoy en día, en general, el precio del agua no refleja todos los costes generados por las instituciones, la sociedad y el medioambiente.

Para poder recuperar estos costes a través de una estrategia de precios, es necesario en primer lugar identificar el concepto de “recuperación”, a través de la evaluación de los componentes del “coste total” con exactitud razonable. Los costes de los servicios son fáciles de calcular. El artículo 2 define los costes de servicio en dos categorías generales: distribución de agua y tratamiento de aguas residuales. A estos costes se le deberán de añadir los costes administrativos, los de monitoreo y el resto de los costes necesarios para alcanzar los objetivos de la DMA. Sin embargo los costes ambientales son más difíciles de calcular. Las pérdidas del hábitat, los cambios en los ecosistemas acuáticos debidos a cambios en la calidad, cantidad y temperatura del agua son difíciles de analizar desde una perspectiva ecológica, más aún lo será el atribuirle un valor económico.

De la misma manera es difícil realizar una calculo de los costes de oportunidad en los que se incurre cuando un determinado uso del agua impide o imposibilita otro uso. Un análisis económico del sector del agua debería de tener en consideración los subsidios que afectan al uso sectorial del agua y las consecuencias de los mecanismos de sistemas de precios. Este tipo de análisis requerirá la aplicación de métodos de evaluación de alternativas que permitan la ampliación del conjunto de criterios de comparación, aún en el caso de que no se puedan atribuir valores. El análisis multicriterio, la valoración contingente y los precios hedónicos son tres enfoques que pueden ser aplicados para analizar el valor económico del daño ambiental.

El análisis de los costes es solamente el primer paso. La redefinición del sistema de precios que refleje los costes reales del agua podría incrementar radicalmente el precio de la misma para los consumidores. Los efectos para los agricultores y para los productos agrícolas podrían ser dramáticos. ¿Es de esperar que los usos del agua den lugar a este incremento de los precios? Los costes de implementación de la DMA son sustanciales. Chave apunta una serie de estimaciones de la Comisión y del Reino Unido, mostrando que los costes de cumplimiento de la DMA se pueden estimar en un margen de entre 4.9 y 17.4 billones de euros.

Aspectos Sociológicos

La DMA establece específicamente en su artículo 14 el proceso de consulta e información pública. Los Estados miembros son obligados a involucrar al público en la implementación de la DMA publicando la información específica relativa a los Plan Hidrológico de Cuenca abriendo la posibilidad al público de reflejar sus comentarios acerca del proceso de planificación. Este tipo de interacciones deben realizarse uno, dos y tres años antes del período al que hace referencia el Plan de Cuenca. El resto de la información y documentación de base referente al Plan de Cuenca deben estar disponibles bajo solicitud. Se anima además, a los Estados miembros, a involucrar de manera activa a todas las partes interesadas, requiriendo algo más que la simple publicación de información. La participación de los actores interesados en el proceso de planificación puede realizarse de diversas maneras, entre las cuales la realización de foros públicos, o el uso de grupos de trabajo especializados o del uso de programas informáticos para la toma de decisiones en grupo. Todas estas alternativas en cualquier caso, conllevan una serie de implicaciones sociales que dependen de como estén distribuidos los derechos y las responsabilidades dentro de la sociedad.

La dimensión social de la sostenibilidad es normalmente la última en ser abordada en la gestión de estrategias y políticas ambientales. Esto puede verse reflejado en esta innovadora Directiva al definir los criterios ambientales y económicos de manera más precisa que los sociales. Es justo decir que hasta el momento no existe un adecuado consenso de cuales deberían ser los criterios de sostenibilidad social (Omann y Spangenberg, 2002), y esto es un factor que contribuye a esta aparente carencia de objetivos sociales en muchos políticas que tratan de fomentar el desarrollo sostenible. De cualquier modo, es necesario integrar criterios de diverso tipo y tener en cuenta la importancia que les es atribuida por parte de los diferentes actores.

La DMA sienta las bases para la sostenibilidad social estableciendo la participación pública en los procesos de planificación como una práctica común. Incluso si el nivel de la participación es el más básico, para algunos países europeos, este es un paso necesario ya que en muchos casos los ciudadanos no tienen ningún papel legítimo en la gestión del agua. La Tabla 1-1 refleja algunos niveles de participación pública en la planificación así como el efecto que esta participación tiene en la distribución de poder.

El carácter socio-político de una sociedad viene determinado en gran medida por la capacidad de control decisional que es devuelto a la comunidad para la gestión de los recursos naturales y por el papel que juegan la autoridades públicas. Para algunos Estados miembros, el artículo 14 puede ser el reflejo de un escenario existente en el que este tipo de intercambio de información se realiza de alguna manera en la actualidad. Esto significa que los canales de comunicación ya están establecidos y que tanto los actores a nivel individual como de grupo esperan la oportunidad para comentar las propuestas de planificación. Para otros Estados miembros, es posible que no existan muchos antecedentes de tales interacciones, lo que hace que la aplicación del citado artículo sea más difícil. Puede resultar muy costoso establecer nuevos canales de comunicación y los mecanismos para la recogida y tratamiento de la opinión pública, y además, este tipo de procedimientos puede ser incompatible con los actuales enfoques de planificación. Más aún, puede que existan reticencias a lo que sería un paso hacia la redistribución de poder que amenaza la libertad de de los individuos o de las organizaciones a tomar decisiones de una manera no transparente.

Control	Nivel de participación	Ejemplos
Alto	Tiene control	La institución solicita de la comunidad la identificación del problema y toman las decisiones claves referentes a objetivos y medios. Disponibilidad de ayudar a la comunidad en cada paso para lograr los objetivos.
	Tiene autoridad delegada	La institución identifica y presenta el problema a la comunidad. Define los límites y solicita de esta tomar decisiones que serán incorporadas en el plan que será aceptado.
	Planifican conjuntamente	La institución presenta una propuesta de plan que está sujeta y abierta a los cambios propuestos de aquellos que se verán afectados.
	Es consultada	La institución trata de promover un plan. Trata de buscar el apoyo que facilite por lo que se espera la conformidad administrativa
	Recibe información	La institución hace el plan y lo aprueba. La comunidad es convocada con fines informativos. Se espera la conformidad
Bajo	Nada	La comunidad no dice nada

Tabla 1-1: Escala de participación de la comunidad: grado de participación y ejemplos para alcanzarla (WHO, 1999)

El segundo punto de la DMA que hace referencia a los aspectos sociales es el enfoque de la gestión internacional de las cuencas hidrológicas. Aunque durante muchos años se hayan establecido entre estados medidas de colaboración para la gestión de ríos fronterizos, se necesitarán mayores esfuerzos para mejorar la colaboración para poder alcanzar los niveles de intervención establecidos en el programa de medidas de la DMA (Chave, 2001). En la actualidad, los acuerdos existentes pueden sentar las bases para la definición de las autoridades competentes para la aplicación de la DMA, pero la asignación de responsabilidades prevista en la DMA será una tarea larga y compleja.

Este tipo de colaboración internacional para el desarrollo sostenible de un determinado territorio de alguna manera, carece de precedentes. La identificación de una comunidad ligada a una cuenca hidrográfica puede poner en duda los derechos y las responsabilidades preestablecidas así como la distribución de poder entre naciones, de la misma manera que el aumento de la participación pública estimula el cambio en el control desde la autoridad hacia el público en general. Este tipo de esfuerzos son una reafirmación de la importancia de la calidad ambiental y el papel de la comunidad como garante de la misma obligando a la Comunidad Europea y sus vecinos a trabajar de manera conjunta de manera más cooperativa para la gestión sostenible del agua, la Comisión, con su DMA, está promoviendo el desarrollo de una sociedad más sostenible.

1.3.4 La Estrategia de Implementación de la Comisión

Claramente, con la introducción de un texto normativo como la DMA que será aplicada a lo largo de la Comunidad Europea, y que establece procesos de monitorización costosos, cambios en los límites territoriales, reorganización de las instituciones y, en algunos casos una redistribución de poder, el éxito del logro de los principios establecidos en ella dentro de un periodo de tiempo razonable es un asunto bastante delicado. En mayo de 2001, la comisión publicó la Estrategia Común de Implantación (*Common Implementation Strategy*, CIS), que ha sido diseñada para establecer la estrategia que permita una aplicación "coherente y harmonizada" de la DMA.

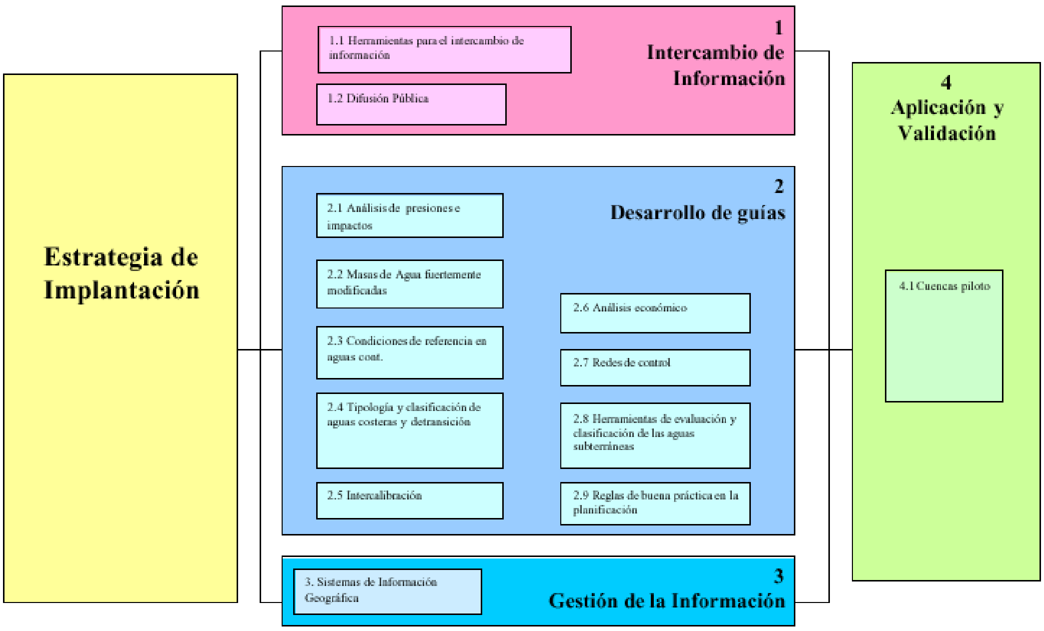

Figura 1-2: Estructura de la Estrategia Común de Implantación (UE, 2001)

Esta estrategia común reconoce alguno de los retos de la implementación: el calendario exigente; la complejidad del texto de la DMA; la variedad de soluciones posibles a ciertos punto establecidos en la DMA; el problema de capacidad de colaboración; y una base técnica y científica incompleta (UE, 2001). Centrándonos en los aspectos metodológicos, los resultados de esta estrategia común, incluirán documentos de guía para aclarar y desarrollar los aspectos técnicos y científicos para la aplicación práctica de los puntos y definiciones generales.

La CIS de la DMA tiene una estructura modular basada en cuatro actividades clave: 1. *Intercambio de información*; 2. *Desarrollo de Guías*; 3. *Gestión de la Información*; 4. *Aplicación y validación*. Cada una de estas actividades está dividida en subproyectos tal y como se muestra en la estructura general de la Figura 1-2. Cada uno de los subproyectos es gestionado por un grupo de trabajo y la responsabilidad para la coordinación de las actividades es distribuida a alguno de los socios de la Comisión Europea y de los Estados miembros.

Grupo de trabajo	Socios
Análisis de presiones y de los impactos	Reino Unido, Alemania
Masas de agua fuertemente modificadas	Alemania, Reino Unido
Condiciones de referencia en aguas continentales	Suecia
Tipología y clasificación de aguas costeras y de transición	Reino Unido, España, Agencia Medioambiental Europea (EEA)
Sistemas de Información Geográfica	EC-Joint Research Centre (JRC)
Intercalibración	JRC
Redes de control (*Monitoring*)	Italia, EEA
Análisis Económico	Francia, Comisión Europea
Herramientas de evaluación y clasificación de las aguas subterráneas	Austria
Reglas de buena práctica en la planificación de Planes de Cuenca	España

Tabla 1-2:Grupos de trabajo de la ECI (Jones, 2001)

De esta forma, a través de la participación en el proceso del ECI los Estados miembros tendrán un apoyo adicional en la implementación de la DMA casi inmediato a través del intercambio de experiencias con otros países y la guía general proporciona por la Comisión. A pesar de los esfuerzos propuestos por la ECI, ha tenido una cierta cantidad de críticas acerca del nivel efectivo de participación que ha existido en este proceso, tanto por la consideración de público en general como con respecto a los mismos Estados miembros.

La importancia de las actividades clave para las fases siguientes del proceso de implementación de la DMA, se pueden derivar de los plazos establecidos por la Directiva. Las limitaciones de tiempo ha sido un tema de gran preocupación a lo hora de poner en práctica la DMA. Los Estados miembros necesitarán determinar con la información disponible, los cambios institucionales requeridos antes de que estén disponibles los primeros resultados del proceso de la ECI.

El texto de la DMA establece los plazos para su conformidad legal tal (ver tabla 1-3).

Plazos Mínimos de Conformidad -Tareas DMA	
Final 2003	DMA transposición a la legislación nacional Identificación de los Cuencas Hidrográficas
Final 2004	Finalización del Análisis de las presiones y los impactos Finalización del Análisis Económico
Final 2006	Programas de monitorización operativos Consulta pública de los elementos del Plan Hidrológico de Cuenca (RBMP)
Final 2009	Publicación de los Planes Hidrológicos de Cuenca
Final 2010	Establecimiento de las Políticas de Precios
Final 2012	Programas de medidas operativos
Final 2015	Objetivos ambientales alcanzados

Tabla 1-3 Tareas de la DMA con los plazos mínimos de conformidad. (Jones, 2001)

Con el fin de logar una gestión efectiva de las cuencas, los Estados miembros deberán trabajar de manera paralela en diferentes tareas, iniciando dichas tareas lo antes posible. De hecho podría ser un error el permanecer pasivo mientras el proceso de transposición está en curso. Si los Estados miembros deciden tomar la iniciativa de comenzar a aplicar los procesos de planificación descritos en la Directiva usando la información disponible hasta donde sea posible, aunque los resultados no sean perfectos al inicio, estos esfuerzos proporcionarán una información muy útil, que permitirá alcanzar a largo plazo de manera eventual los plazos establecidos y pueden ayudar a gestionar los costes financieros de implementación (Jones, 2001).

En la actualidad, nos encontramos a las puertas de la publicación de los planes hidrológicos de cuenca y tal y como refleja la comunicación COM(2007) 128 de la Comisión de las Comunidades Europeas, los informes de los Estados miembros sobre la implementación de la Directiva son alentadores, aunque “se observan graves deficiencias en algunos campos”. Estas graves deficiencias están relacionadas por un lado con la deficiente transposición de la Directiva a la legislación nacional que debería haberse realizado a finales de diciembre de 2003. En este sentido la Comisión se ha visto obligada a incoar once procedimientos de infracción a diferentes Estados y algunos países como Bélgica, Luxemburgo, Alemania, Italia o Portugal han recibido sentencias en contra del Tribunal de justicia por no notificar la transposición de la Directiva. Aún así, la evaluación realizada por la Comisión sobre la calidad de la transposición ha dejado patente que la mayoría de los casos la Directiva no se ha incorporado plenamente al ordenamiento jurídico a nivel nacional en relación sobre todo a los artículos 4, 9 y 14 que hacen referencia a los objetivos ambientales, a la recuperación de costes de los servicios relacionados con el agua y a la información y consulta pública respectivamente.

Puede decirse que los retos que los Estados miembros se habían propuesto con la implantación de la DMA están todavía lejos, pero no son inalcanzables y se ha progresado considerablemente en el camino hacia una gestión sostenible e integrada del agua en Europa.

1.3.5 La Directiva Marco del Agua y la gestión del agua a nivel nacional

La primera tarea para cada uno de los Estados miembros será la ratificación de la DMA y su transposición a la legislación nacional antes del final del 2003. Tal como hemos visto con anterioridad, la transposición incluye, primero, la definición de las demarcaciones hidrográficas nacionales e internacionales. En segundo lugar, requiere de los Estados miembros la designación de una autoridad para la implementación del plan de gestión de cuenca en el seno de cada cuenca.

Aunque estos requerimientos son iguales para todos los países europeos que han firmado la DMA, las actuales políticas de agua y legislación en vigor son diversas, lo que implica diferentes potencialidades y estrategias de adaptación.

Se presentan a continuación, de manera resumida, algunos resultados de un estudio de las políticas de agua en Italia, uno de los países que ha participado en el proyecto MULINO[1], y que permite ilustrar las principales ventajas y desventajas para la implementación de la DMA.

En Italia, desde la década de los 70, se ha producido un claro proceso de división de poderes a nivel local y con ello una descentralización de la toma de decisiones relacionada con la gestión de los recursos hídricos. El régimen del agua se caracteriza por un incremento del grado de complejidad a través de la implicación de un número, cada vez mayor de actores. La nueva jerarquía de gestión parte desde el nivel nacional, regional provincial y llegando a nivel local. Las políticas del agua a nivel nacional están estrechamente relacionadas con las políticas a nivel europeo. Las principales instituciones para la gestión de los recursos hídricos están compuestas por: el Ministerio del Medioambiente, el Ministerio de Obras Públicas, el Ministerio de la Salud, el Ministerio para la Coordinación de Políticas Comunitarias y la Agencia Medioambiental Nacional. A nivel regional las autoridades con competencias en materia de agua son las Agencias Regionales del Medioambiente y las Autoridades de Cuenca. La transposición de la DMA no requiere una revisión exhaustiva de la estructura de gestión actual, pero si de la identificación de las competencias y de la distribución de los recursos financieros.

[1] MULINO, es un acrónimo utilizado para *MULti-sectorial, INtegrated and Operational decision support system*, es un proyecto financiado por la Comisión Europea que se centra en el uso sostenible de los recursos hídricos a nivel de cuenca

En 1999, el Decreto Legislativo N. 152/1999 de la ley italiana tenía como objetivo la integración de las políticas ambientales, de salud, económicas y productivas hacia una política global para la gestión de los recursos de agua. Los intentos de integración se realizaron a dos niveles, a nivel regional con las Instituciones de gestión de cuenca y a nivel local a través de la creación de las Áreas Territoriales Optimas (Goria y Lugaresi, 2002 y 2004). Tal reforma no tuvo ningún éxito porque el nivel de la complejidad del proceso de descentralización ha generado conflictos y contradicciones que reflejan los obstáculos principales del proceso de la reforma estatal italiano. Sin embargo, el nivel de escala establecido en de las cuencas establecidas en la DMA es más amplio que los dos niveles existentes de la gestión italiana de los recursos hídricos. Si las contradicciones actuales están afectando claramente la eficacia de la gestión, la nueva delimitación espacial requerida por el DMA podría ser una oportunidad para solucionar los conflictos existentes.

El nivel internacional de la gestión del agua que proporciona la DMA puede ser en principio, una forma de conseguir resolver algunos conflictos nacionales de redistribución de la autoridad dentro de las jerarquías nacionales de la gestión del agua. En cualquier caso, aunque si bien se espera definir muy pronto los límites de las cuencas, es difícil a estas alturas creer que la reestructuración de la estructura de gestión del agua sea operativa en las cuencas dentro de los plazos establecidos por la Unión Europea.

1.4 NUEVOS ASPECTOS EN LA GESTIÓN DE LOS RECURSOS HÍDRICOS

Tal y como se ha indicado, la entrada en vigor de la DMA supone, además de su objetivo final de alcanzar el buen estado ecológico de las aguas, el poner en práctica nuevos aspectos en la gestión de los recursos hídricos. En esta sección trataremos de reflejar la gran complejidad de los problemas relacionados con la gestión del agua (uso múltiple, escasez y conflicto) lo que justifica la importancia del análisis multicriterio para afrontar los problemas de ayuda a la elaboración de políticas en un contexto integrado y sostenible de la gestión del agua.

El agua es un recurso natural que siempre ha desempeñado un papel estratégico en el desarrollo social y económico aunque este papel sea diferente según la escala geográfica y temporal.

Es muy difícil generalizar los problemas específicos que conciernen a la gestión integrada del agua y que dependen de aspectos físicos, sociales y económicos. En otras palabras, no es fácil encontrar un modelo común para la gestión del agua en África o en Este Asiático o en la planicie Veneta. En algunos casos el agua puede ser considerada como un enigma económico. Sin embargo, si es posible identificar ciertas pautas generales en lo referente a las características socioeconómicas.

El agua puede ser considerada de la siguiente manera:

- El agua es un componente fundamental del ecosistema terrestre. Es esencial para las funciones biológicas primarias y la vida no puede ser concebida sin la existencia de agua.
- El agua es un derecho humano, desde el momento que es considerada como una necesidad básica; es un bien indispensable para el desarrollo normal de las actividades humanas en las que la calidad y la cantidad condicionan de manera importante la calidad de vida;
- El agua es un factor de producción, cuando es usada con fines productivos y desde el momento que afecta a la cantidad y la calidad de las posibilidades de producción. De hecho la escasez de agua o el exceso de la misma puede ser por un lado un recurso básico o por el otro restringir la producción;
- El agua es un bien de lujo, que asegura ciertos estándares de vida; las sociedades económicamente más avanzadas están incrementando la demanda de agua con fines recreativos para muchas actividades de ocio relacionadas con el agua.

En la situación actual, los recursos hídricos son utilizados con diversos fines y gestionados por diferentes instituciones que poseen, a su vez, objetivos diferentes que en ocasiones entran en conflicto. De hecho, además de la función civil y de producción, el agua debe ejercer una función de protección para la salvaguardia del ambiente, una función recreativa cuya demanda se ha incrementado en los últimos años en relación a las otras funciones, representando a su vez un interés económico de las zonas húmedas, los ríos y los lagos.

Los diferentes usos del agua pueden ser representados a través de los flujos en los sistemas superficiales y subterráneos. En general, se pueden considerar cinco diferentes usos del agua: generación de energía, riego en la agricultura, agua potable para uso humano, factor de producción para la industria, y para uso recreativo. Los flujos de salida representan la demanda para cada uno de los usos, que normalmente entran en conflicto debido a la limitación de la cantidad y calidad del agua disponible. Los flujos de entrada representan los retornos al sistema, que normalmente lo hacen en condiciones de cantidad y calidad peores, por lo que dependiendo de la capacidad de carga del sistema, la calidad de los flujos de entrada se puede ver reducida. Todos los flujos, tanto de entrada como de salida están altamente interrelacionados y dependen los unos de los otros. Por ejemplo, un embalse puede satisfacer diferentes usos al mismo tiempo: electricidad, agua para el riego, para el consumo humano y para la industria.

En el caso de la agricultura el aspecto más crítico es la cantidad de agua (sobre todo en estaciones más secas): los flujos de salida provienen de aguas superficiales y de aguas subterráneas, pero el uso excesivo de fertilizantes puede reducir la calidad del agua del sistema en su retorno afectando de manera significativa a los demás flujos del sistema. Para el consumo humano el aspecto más importante es la calidad del agua, íntimamente relacionada con las condiciones de salud, pudiéndose considerar como un bien básico o de primera necesidad. Los flujos de entrada al sistema provenientes del uso humano, es decir, las aguas residuales afectan de manera significativa a la calidad del agua para usos posteriores.

En cuanto a la industria, esta requiere normalmente una gran cantidad de agua y es la causante de la mayor parte de los problemas de los sistemas hidrológicos con los flujos de entrada del agua usada en los procesos productivos. Para uso recreativo el aspecto más importante es la calidad del agua: actividades como la pesca, deportes acuáticos, etc. dependen fundamentalmente de la calidad del agua. Desafortunadamente, en las regiones menos favorecidas del planeta, el crecimiento de la población ha dado lugar a un incremento de la contaminación de origen domestico, agrícola e industrial acompañado de una disminución de las cantidad de agua disponible y un deterioro de la calidad.

De acuerdo con estos diversos usos del agua bajo el punto de vista social y económico, el agua es un bien que presenta diversas características en lo que se refiere a los derechos de propiedad y competencias de su uso.
Dependiendo de cada caso el agua puede ser considerada como:

- Un bien privado (mercado del agua, agua embotellada, etc.);
- Un bien de libre acceso (agua para beber, aguas subterráneas);
- Un bien común gestionado por comunidades o instituciones locales (regadíos, gestión del agua por las Confederaciones Hidrológicas).

Considerada como un bien privado, el agua se convierte en un bien económico puro, con un precio establecido en el mercado a través del juego de la oferta y la demanda. Considerada como un bien de libre acceso, todo el mundo puede acceder al agua al ser considerada un bien de primera necesidad. Como un bien común el agua es considerada como un bien de interés público para el cual se establecen ciertas restricciones de uso.

Un aspecto fundamental a tener en cuenta es que, sea cual sea el uso o la propiedad, el contexto decisional actual de la gestión del agua se verá radicalmente modificado por la conflictividad en su uso a lo largo del mundo. Ejemplos de ciertos aspectos que han originado conflictos en el uso del agua son:

- Crecimiento de la población (particularmente en áreas donde la escasez de agua es bastante corriente);
- Cambios en la importancia entre los sectores económicos y creciente interés en el medioambiente;
- Competitividad entre los sectores civil, industrial y agrícola.

La situación es, por lo tanto bastante complicada, lo que supone serios problemas para encontrar pautas para el desarrollo de modelos de gestión del agua. Lo que si es claro, es que es necesario encontrar un compromiso en la consideración del agua como un bien publico de libre acceso y un bien puramente económico para la optimización de su uso. Este objetivo supone encontrar una solución institucional que pueda resolver estos problemas, y estas se pueden resumir en dos: el mercado y la gestión común.

Nosotros creemos que el mercado puede funcionar relativamente bien en las economías más desarrolladas si es concurrente con su uso como factor de producción. La competencia puede asegurar un uso más eficiente fijando precios y desincentivando la contaminación. En el resto de los casos, es decir, el agua como bien de primera necesidad y como requisito medioambiental, el mercado plantea problemas de eficacia y equidad. La DMA propone una serie de medidas que deberían proporcionar un efecto similar al del mercado pero en este caso aplicado en un contexto público.

Desde esta perspectiva, la nueva gestión del agua impulsada por la aplicación de la DMA, implica que las decisiones en materia de gestión de agua han de ser alcanzadas incorporando de forma sistemática los múltiples objetivos y niveles de aspiración de los diferentes decisores que en ocasiones pueden entrar en conflicto. Además se hace necesario que en todo este proceso quede reflejado igualmente los intereses del resto de organismos competentes, instituciones afectadas y el resto de usuarios y público en general. Todo ello supone la puesta en práctica de un proceso de negociación que ha de ser iterativo y por consiguiente interactivo que por si mismo representa una de las partes más importantes de la resolución de conflictos.

Así pues la gestión integrada del agua, como señala Bogardi (1994) y que podría aplicarse bajo la nueva perspectiva de la DMA, puede ser considerada como un problema decisional complejo en el que nos encontramos con decisores con diferentes puntos de vista que representan intereses públicos y privados, con diferentes niveles jerárquicos de decisión influenciados por restricciones de tipo físico, económico y social.

Del mismo modo la consideración de escenarios futuros, como la buena calidad de las aguas para el 2015, supone la consideración de múltiples objetivos y criterios para su logro y con ello su representación en diferentes escalas numéricas (ordinales y cardinales) así como descriptivos.

Nos encontramos pues, con el dilema de utilizar métodos de evaluación cada vez más complejos que representen de forma adecuada el aspecto integrador en la gestión tal y como se propone en la Directiva. Al mismo tiempo dichas técnicas han de ser lo suficientemente simples que permitan una participación activa de todos los actores implicados en un proceso decisional transparente sin que por ello se comprometa la calidad de las decisiones tomadas.

Todo este tipo de consideraciones hace que surjan serias limitaciones a la hora de aplicar los métodos neoclásicos utilizados habitualmente en la evaluación de políticas públicas relacionadas con los recursos naturales basados y que están basados principalmente en la reducción a términos monetarios de estos aspectos: el análisis coste-eficiencia o coste-beneficio. Los nuevos retos y objetivos de la DMA hacen del análisis multicriterio una metodología más adecuada para abordar esta tipología de problemas, considerando los métodos basados en el coste como un elemento más del proceso de evaluación basados más en la eficacia de las políticas que en sus beneficios que son de difícil representación económica.

CAPÍTULO 2

OBJETIVOS Y METOLOGÍA

2. OBJETIVOS Y METODOLOGÍA

2.1. OBJETIVOS

La demanda de agua y por ende los conflictos derivados de la misma, están aumentando continuamente de Europa. Prácticamente todas las actividades humanas de una forma directa o indirecta hacen uso el agua, por lo que la demanda de agua para las diferentes actividades se hace si cabe más evidentemente en áreas donde este recurso comienza a ser escaso. La demanda de agua puede decirse que varía considerablemente en términos de la escala, origen, naturaleza e intensidad. La cantidad de normativa existente a diferentes niveles administrativos, conjuntamente con la complejidad de los contextos decisionales, ha presionado a los organismos encargados de la gestión del agua para que recojan, procesen y organicen cada vez un mayor volumen de información necesaria para la toma de decisiones.

La entrada en vigor de la nueva Directiva Marco del Agua y su trasposición a la legislación nacional, identifica una serie de principios hacia los cuales los diferentes Estados Miembros deben orientar sus esfuerzos en los próximos años. De entre todos ellos podemos destacar los siguientes:

- Necesidad de identificar las estructuras administrativas que gestionan el agua basándose en el flujo natural de las aguas superficiales y subterráneas dentro del ciclo hidrológico, y por tanto, identificar las unidades de cuenca como área de referencia para la gestión del agua a nivel local;
- necesidad de una mayor integración de los aspectos cuantitativos y cualitativos de la gestión de las aguas tanto de las aguas superficiales como subterráneas, lo que requiere herramientas capaces de integrar dichos aspectos;
- la importancia de “asegurar la participación del público en general y de los usuarios individuales del agua”,
- la necesidad de un sistema de vigilancia sistemático que permita la comparación por parte de toda la comunidad, lo que supone un sistema de información unificado;

La aplicación de la Directiva y por tanto, la necesidad de alcanzar una gestión integrada del agua por parte de las administraciones públicas, ha llevado a una demanda creciente de instrumentos operativos que ayuden en el proceso de toma de decisiones. En los últimos años se han constatado muchos avances en el desarrollo de herramientas, técnicas y modelos para la ayuda a la decisión de este tipo de problemas.

Parte de estos esfuerzos ha dado como fruto el que durante este tiempo, se haya generado, y se siga generando todavía, una buena base de conocimiento científico en diferentes áreas que están estrechamente relacionados con la gestión del agua: la modelización hidrológica, la evaluación de impacto ambiental, la valoración económica de los recursos naturales, así como una metodología, el análisis multicriterio, que teniendo un campo de utilización más amplio, tiene sus orígenes en la gestión de recursos naturales. Sin embargo, en la mayoría de los casos, estos estudios se han realizado de manera aislada, y aunque los estudios integrados son cada vez más numerosos, existe todavía una carencia substancial de enfoques verdaderamente multidisciplinarios lo cual sigue siendo un obstáculo para la puesta en práctica de muchos aspectos prioritarios de la gestión del agua.

En este sentido el análisis multicriterio está ampliamente considerado como una herramienta útil en la resolución de conflictos relacionados con la gestión del agua. Esta utilidad se basa fundamentalmente en el empleo de una estructura lógica de los procedimientos de evaluación y en el lenguaje común desarrollado para definir y discutir complejos problemas hídricos. A su vez, puede considerarse como una herramienta muy útil cuando se persiguen objetivos de comunicación y diseminación de información entre aquellos que toman las decisiones en el ámbito público y político, y aquellos que se ven afectados por éstas. Por último, otra de las ventajas que proporcionan el uso de estas técnicas, es la facilidad para incorporar en el análisis el efecto de la incertidumbre que generalmente caracteriza a los problemas de la gestión del agua.

Así pues, el primer paso para establecer los objetivos de esta línea de investigación fue el tratar de identificar aquellos aspectos que de un modo u otro, justificaban la necesidad de abordar la gestión de los recursos hídricos desde otra perspectiva:

- La integración que se realiza de estas disciplinas es, en muchos casos incompleta o supone la subordinación de una disciplina a otra.
- Se puede afirmar que todavía existen diferencias funcionales entre la comunidad científica y el mundo real, sobre todo a la hora de considerar la implicación en los procesos de gestión de los usuarios potenciales.
- Debido a estos dos aspectos, suelen existir grandes diferencias entre los avances que se producen en la investigación y la manera en que dichos avances son aplicados en el mundo real a través de herramientas operativas.

El **objetivo principal** de esta investigación ha sido desarrollar, evaluar e implementar un sistema de ayuda a la decisión al amparo de un proyecto de investigación europeo, que permitiera a las administraciones públicas disponer de una herramienta que permitiera manejar una cantidad de información cada vez mayor y más heterogénea, para poder llevar a cabo una gestión sostenible de los recursos hídricos a nivel de cuenca hidrográfica.

Para lograr este objetivo se propone seguir un enfoque de desarrollo orientado a la operatividad final del sistema, tratando de integrar la base científica del modelo y las experiencias previas recogidas en la literatura, con el conocimiento y las necesidades de los usuarios finales en un proceso continuo e iterativo de retroalimentación que permita ajustar al máximo el conocimiento científico y la gestión pública.

A su vez, el objetivo general de la investigación se puede descomponer en una serie de objetivos específicos que se tratarán en los diferentes trabajos presentados:

1. Definir un enfoque metodológico que permita abordar la mayoría de los problemas decisionales que se plantean en la gestión integrada del agua desde el punto de vista de las administraciones públicas.
2. Establecer un marco de referencia conceptual de la gestión sostenible de los recursos hídricos.
3. Establecer mecanismos de participación publica en los procesos de planificación del agua.
4. Diseñar y desarrollar de una herramienta operativa de ayuda a la decisión que permita integrar modelización hidrológica, indicadores e índices multidisciplinarios y procedimientos de análisis multicriterio para la gestión del agua.
5. Probar la herramienta en casos de estudio representativos con la colaboración tanto de los actores implicados como de los usuarios finales del software.

1. Definir un enfoque metodológico que permita abordar la mayoría de los problemas decisionales que se plantean en la gestión integrada del agua desde el punto de vista de las administraciones públicas

La necesidad de definir un enfoque metodológico se deriva directamente del marco de trabajo establecido por la Directiva Marco de Agua. La trasposición a la normativa nacional y la puesta en práctica de la Directiva supone un desafío para cada uno de los estados miembros ya que su éxito estriba en la homogeneidad y la coordinación de su aplicación.

Al establecerse un tipo de planificación y gestión a nivel de cuenca hidrográfica, ha de tenerse en cuenta que en muchos casos ello supone la implicación de diversas autoridades administrativas (locales, regionales e incluso nacionales), hace que sea necesario que todos los estados miembros tengan una visión conjunta y uniforme de la forma en que se aplique. Para ello se ha utilizado un procedimiento no vinculante que es la Estrategia Común de Implantación, con una serie de grupos de trabajo encargados de desarrollar guías de actuación o recomendaciones específicas para diferentes ámbitos de la Directiva.

Uno de los retos a los que se deben enfrentar todas las autoridades responsables de la gestión del agua es precisamente la coordinación de sus actividades de gestión. Para ello es necesario comprender en primer lugar, las implicaciones a nivel administrativo que supone la aplicación de la Directiva, así como reconocer las posibles fuentes de conflicto que puedan surgir. En segundo lugar, es necesario establecer un enfoque metodológico que permita dicha coordinación y afrontar de forma clara y comprensible la estructuración de los problemas que se pretenden resolver.

Se propone definir un enfoque metodológico partiendo de un marco conceptual ampliamente usado y reconocido a nivel europeo. El modelo DPSIR (*driven forces, pressure, state, impact, response*) desarrollado inicialmente por la Agencia Europea de Medio Ambiente para realización de informes en materia de medio ambiente y que estructura los problemas ambientales formalizando las relaciones e interacciones entre la actividad antrópica y la actividad ambiental como cadenas de relaciones causa efecto.

Así pues este objetivo trata de resaltar las dificultades con las que se encuentran las administraciones públicas a la hora de enfrentarse a decisiones en el campo ambiental y en particular en la gestión del agua desde la perspectiva de la aplicación práctica de la Directiva. Para ello se propone el uso de los métodos multicriterio de ayuda a la decisión basándose en el marco conceptual DPSIR como una metodología que facilite los procesos de planificación y decisión en un contexto de gestión sostenible e integrada del agua.

2. Establecer un marco de referencia conceptual de la gestión sostenible de los recursos hídricos.

Uno de las principales carencias a la que se enfrenta la gestión integrada del agua, es precisamente la ausencia de un marco de referencia conceptual claro y preciso. En los últimos años, y sobre todo a raíz de la publicación del llamado Informe Brutland, han sido innumerables la aparición de conceptos y definiciones relacionados con el medio ambiente y que han tenido un impacto y una repercusión a nivel mundial.

Para su aceptación y reconocimiento internacional, en la mayoría de los casos, estos conceptos e ideas han sido propuestos fundamentalmente a nivel político. No cabe duda de que ello ha supuesto un gran avance en la gestión de los recursos naturales, sin embargo, este proceso se ha realizado de forma simultánea y superpuesta, no existiendo una definición reconocida unánimemente y precisa de los límites e implicaciones conceptuales de cada uno de ellos. Ello supone una dificultad añadida para los administradores y gestores de los recursos a la hora de poner en práctica los nuevos principios e instrumentos de la política ambiental a nivel regional y local.

Así pues, se ha considerado que es necesario hacer una revisión de los distintos conceptos y definiciones existen en la literatura, en primer lugar a nivel genérico en lo que respecta al medio ambiente y en segundo lugar se tratar de analizar aquellos relacionados directamente con la gestión del agua.

3. Establecer mecanismos de participación publica en los procesos de planificación del agua.

Como ya hemos indicado anteriormente, la DMA establece en su artículo 14 la necesidad de realizar un proceso de consulta e información pública que supone un nuevo reto en la aplicación de políticas comunitarias en materia de recursos naturales. Ello supone que todos los actores involucrados en el proceso de gestión del agua, ya sean decisores, gestores o usuarios, afectados directa o indirectamente por los Planes hidrológicos de Cuenca, han de tener la posibilidad de expresar sus comentarios y opiniones al respecto.

Sin embargo la Directiva no especifica a que nivel ha de llevarse a cabo este proceso de participación pública, aunque recomienda una participación activa de las partes, ni los mecanismos a través de los cuales la opinión pública podrá verse reflejada en el proceso de planificación..

Por otro lado hemos de tener en cuenta las implicaciones sociales que un proceso de estas características puede tener, ya que la distribución de derechos y responsabilidades es muy heterogénea en cada uno de los estados miembros con lo cual el proceso de participación pública ha de ser afrontado de forma diferente en países con una mayor tradición en este tipo de actividades que en países donde la participación pública en procesos de planificación es más recipiente y no existe una conciencia clara de su importancia.

Debido a este tipo de condicionantes, se nos antoja complicado establecer un mecanismo completo de participación pública que pueda ser lo suficientemente flexible para abordar las particularidades sociales de cada uno de los estados miembros.

Así pues, nuestro objetivo será en este caso, proponer un mecanismo de participación pública a través del desarrollo de la metodología propuesta, de tal modo que permita la comunicación entre las partes de una forma intuitiva y transparente. De igual modo se pretende que los diferentes actores involucrados, puedan reconocer de algún modo en que medida sus opiniones, juicios o preferencias se ven reflejadas en el proceso de planificación.

El objetivo por tanto se centra en abordar este requerimiento social integrando el enfoque DPSIR en una metodología que permite la estructuración y exploración de problemas con los métodos de análisis multicriterio. Teniendo en cuenta las directrices establecidas por la Directiva, este proceso podría llevarse a cabo en grupo y de manera conjunta reuniendo tanto a decisiones como a los actores afectados, usando la metodología propuesta como base para la discusión y la participación colectiva en el proceso.

4. Diseñar y desarrollar de una herramienta operativa de ayuda a la decisión que permita integrar modelización hidrológica, indicadores e índices multidisciplinarios y procedimientos de análisis multicriterio para la gestión del agua.

Para poder afrontar el objetivo del diseño y desarrollo de una herramienta operativa será necesario el haber realizado previamente diversos progresos en los objetivos citados anteriormente. El enfoque metodológico basado en el análisis multicriterio será la base de partida para el diseño de la herramienta, teniendo en cuenta las ventajas y las limitaciones que ello conlleva. Su desarrollo, al tratarse de una herramienta pensada para un uso autónomo por parte del usuario final, es imprescindible que se realice poniendo en práctica un proceso de desarrollo continuo. Este proceso debe proponerse en estrecha colaboración con diferentes usuarios potenciales para confrontar los desarrollos metodológicos con su utilidad práctica.

La utilidad de una herramienta de estas características depende en gran medida de la estructura lógica de los procesos de evaluación y sobre todo del diseño de un interfaz que permita el desarrollo de un lenguaje común para definir y discutir problemas complejos relacionados con la gestión integrada del agua. Asimismo, ha de ser una herramienta lo suficientemente intuitiva que sirva como instrumento de comunicación entre aquellos que deben tomar las decisiones y aquellos que se verán afectados por las mismas. De igual forma, un sistema de información, como el que se pretende desarrollar, debe tener en cuenta las necesidades de información de los usuarios finales. Las necesidades de información condicionan en gran medida los algoritmos de decisión que se pueden implementar. Con todo ello, la herramienta ha de ser capaz tanto de gestionar la información procedente de otros sistemas de información (sistemas de información geográfica en su mayoría) en sus distintas formas cuantitativa o cualitativa, como de generarla de forma directa o a indirecta través de diferentes procedimientos.

La necesidad de agregar información de carácter tan heterogéneo y con orígenes y niveles de precisión tan diverso hace necesaria realizar una profunda revisión de los diferentes enfoques y metodologías de análisis multicriterio en primer lugar, y en segundo lugar de sus aplicaciones en el campo de la gestión del agua. Todo ello teniendo en cuenta los diferentes contextos en los cuales dichas metodologías han sido aplicadas. Con ello se pretende determinar la dilucidar las diferencias en su aplicabilidad de los modelos más precisos a la vez que complejos en relación a los modelos menos precisos pero más intuitivos desde el punto de vista del profano en la materia.

En cualquier caso se pretende evitar el desarrollo de una herramienta que no permita determinar claramente los procesos y metodologías que subyacen en su funcionamiento, aspecto que satisface el requisito de transparencia en procesos de decisión con participación pública.

5. Probar la herramienta en casos de estudio representativos con la colaboración tanto de los actores implicados como de los usuarios finales del software.

El objetivo de probar la herramienta en un caso de estudio ha de entenderse como una de las últimas fases que permiten alcanzar el objetivo principal de esta investigación. Al haberse realizado la investigación teniendo en cuenta las preferencias y necesidades de los usuarios potenciales del sistema de ayuda a la decisión, el proceso de prueba ha de iniciarse ya desde las primeras etapas de su desarrollo.

Para llevar a cabo este objetivo de manera coherente con la necesidad de desarrollar una herramienta que permita abordar diferentes contextos, escalas y problemas, la herramienta necesita ser probada teniendo en cuenta estas premisas. Así pues el proyecto de investigación en el que se enmarca el presente trabajo preveía la puesta en práctica de ocho casos de estudio en cinco países de la Unión Europea (Rumania, Portugal, Reino Unido, Bélgica e Italia), así como una aplicación a escala europea.

En el caso concreto de este trabajo, el objetivo planteado ha sido el probar y evaluar la herramienta en un caso de estudio desarrollado en la península del *Cavallino*, situado en la zona norte de la laguna de Venecia. En dicho caso de estudio que responde a una situación real para la planificación de un nuevo sistema de regadío en dicha zona, se cuenta con la colaboración directa de las autoridades responsables, el Consorcio de Saneamiento del Bajo Piave (asociación de regantes que a su vez son los usuarios finales) y la Región del Veneto.

De igual forma, aunque en un contexto diferente, se propone probar la potencialidad de la herramienta y la metodología para la implementación de las recomendaciones de la Comisión Mundial de Presas (*World Commission of Dams*) para futuros proyectos de presas. En este caso se trata de aplicar la metodología para realizar un estudio a posteriori del proyecto de una presa en *Ceyhan Aslantas* (Turquía) decisión tomada en los años 70. Para el objetivo es utilizar la información disponible en la WCD y tratar de analizar como se llevó a cabo el proceso de decisión siguiendo un procedimiento inverso de “dada la decisión”, cuales han sido los criterios de sostenibilidad seguidos para la elección de la solución final. A la hora de afrontar este estudio han de realizarse un análisis de la incertidumbre asociada a la información utilizada en el proceso de planificación

2.2. METODOLOGÍA

El punto de partida para abordar los objetivos planteados ha sido el análisis de un software de ayuda a la decisión para la gestión sostenible de aguas ya existente denominado mDSS v2.7. Dicho software era a su vez uno de los objetivos principales de un proyecto de investigación europeo denominado MULINO (contrato nº EVK1-2000-22089), finalizado en el 2003 Dicho software, en continua evolución centraba su aportación principal en el concepto de integración, entendido como la capacidad técnica de incorporar datos y modelos analíticos existentes, originados por diferentes fuentes y actores en un sistema de ayuda a la decisión que permitiese de esta manera llevar a cabo un análisis integrado de la gestión del agua.

Así pues, sobre esta base se pretende alcanzar el objetivo principal de la investigación de desarrollar un software flexible que permita dicha integración, mediante un proceso de mejora continua que supone:

- Una revisión de la literatura existente en cada uno de los modelos de estructuración y metodología de análisis relevantes en cada parte del software.
- Un análisis de las necesidades a nivel operativo que se derivan de la gestión integrada del agua.
- Un proceso de contrastación de las soluciones planteadas con los diferentes actores e usuarios del sistema.
- La presentación de los resultados obtenidos ante la comunidad científica.

La revisión de la literatura ha sido uno de los procesos en los que se ha prestado especial atención. Probablemente hasta la fecha, no existan demasiados estudios que hayan recopilado una bibliografía tan extensa en el campo de la gestión integrada del agua. La investigación desarrollada al interno de un grupo multidisciplinar que conformaba el consorcio MULINO, ha permitido acceder no sólo a la literatura fundamental en el campo del análisis multicriterio y los sistemas de ayuda a la decisión, sino también a la bibliografía relevante en otros campos científicos lo que permite tener una visión más integradora, necesaria en el desarrollo de un sistema de información de estas características. Son más de quinientos los artículos e informes que han sido revisados como parte de la investigación.

Por otro lado, son pocos los estudios que realizan un análisis comparativo de los enfoques metodológicos En este sentido, el estudio recogido en el apartado 3 del capítulo 4, es probablemente la recopilación más amplia de las aplicaciones prácticas en el campo del análisis multicriterio relacionado con la gestión del agua que se ha realizado hasta el momento.

El análisis de las necesidades a nivel operativo que se derivan de la gestión integrada del agua supone tener en cuenta serie de premisas que han de tenerse a la hora de aplicar la presente metodología:

- El estudio se centrará en un contexto relacionado con la gestión y planificación hidrológica a nivel de cuenca.
- El ámbito de aplicación se centra en mayor medida en procesos de elección de alternativas que en la generación de las mismas.
- Los conceptos, modelos y metodologías utilizadas han de ser ampliamente reconocidos a nivel internacional y especialmente reconocidos por parte de las administraciones europeas.
- El nivel de complejidad de los modelos ha de adaptarse a los niveles de conocimiento de los potenciales usuarios del sistema.

- No se trata tanto de valorar las diferentes metodologías existentes en cada una de las áreas de conocimiento que se pretenden integrar, sino de valorar la posible integración conceptual de las mismas.

Uno de los principales elementos de discusión que plantean tanto los objetivos como la metodología propuesta en esta investigación es el enfoque estratégico de la misma. Hasta ahora, la mayor parte de los sistemas de ayuda a la decisión existentes en este ámbito se centraban en el desarrollo de complejas metodologías aplicadas en la mayoría de los casos a nivel operativo.

El objetivo, en la mayoría de los casos era el proporcionar soluciones de ingeniería concretas para situaciones y problemas bien estructurados y de los cuales se contaba con una información amplia y detallada y cuyo resultado era bastante preciso. Se ha pasado por tanto de un enfoque complejo basado más en la toma de decisiones (*decision making*) a un enfoque más simple, aunque no por ello menos relevante, basado en la ayuda a la toma de decisiones (*decision support*).

Otro de los elementos que ha suscitado, y que puede suscitar mayor discusión, es la elección de los modelos de agregación. La elección de un método de agregación simple en detrimento de otros más complejos, es el resultado de la necesidad de incorporar al proceso decisional una visión más transparente de los procesos de gestión. La integración de información, opiniones y juicios por parte de diferentes agentes implicados con diferentes niveles de conocimiento y aptitudes de análisis, ha hecho necesario proponer un método común de entendimiento y análisis por parte de todos los agentes.

Tal y como se ha indicado anteriormente la metodología seguida implica un proceso de contrastación de las soluciones planteadas con los diferentes actores e usuarios del sistema. Dicho proceso ha sido llevado a cabo mediante la organización de reuniones periódicas con las autoridades competentes con las que se ha trabajado estrechamente. Así mismo se han invitado a participar a los distintos miembros de los casos de estudio del proyecto a reuniones de carácter internacional donde poder confrontar y discutir sus opiniones específicamente en relación al prototipo desarrollado.

Una vez finalizado el proyecto que ha financiado en parte la presente investigación con la versión mDSS 3.7, el proceso de contrastación y prueba no se ha detenido hasta la fecha. La aplicación de los resultados obtenidos en la elaboración de este sistema de ayuda a la decisión y el sistema mismo, han sido utilizados en otros proyectos de investigación europeos. Este proceso continuo de investigación ha dado lugar a una nueva versión del software mDSS4 que ha sido utilizado entre otros proyectos de investigación:

- NEWATER New approaches to adaptive Water Management under uncertainty,
- NOSTRUM-DSS Network on Governance, Science and Technology for Sustainable Water Resource
- PASARELAS Discovery Modelling Mediation Deliberation — Interface Tools for Multi-stakeholder Knowledge Partnerships for the Sustainable Management of Marine Resources and Coastal Zones
- DSS-GUIDE Guidelines on Decision Support System applications in water resource management

De igual forma los resultados y conclusiones iniciales de los objetivos planteados han sido sometidos, como no podía ser de otra forma, a la presentación, y consiguiente discusión, ante la comunidad científica. Teniendo en cuenta una de las justificaciones presentadas para la realización de este trabajo, se hacía necesario confrontar los resultados no sólo con los miembros internacionales del proyecto de investigación, si no también con expertos destacados en cada una de las áreas de conocimiento que afronta el sistema. Todos los comentarios vertidos en diferentes foros internacionales, así como las opiniones expresadas en las reuniones de los grupo de trabajo de la Estrategia Común de Implantación han sido tenidos en cuenta.

De igual forma este enfoque metodológico eminentemente orientado y basado en la aportación de usuarios y científicos sigue todavía adelante en colaboración con el Ministerio del Ambiente italiano, como soporte en la realización del Plan Hidrológico de Cuenca del río Cecina (Italia), una de las escogidas por la Comisión Europea como ejemplo de la aplicación de la Directiva Marco del Agua.

CAPÍTULO 3

REVISIÓN DE LOS TRABAJOS

3. REVISIÓN DE LOS TRABAJOS

Una vez expuestos los objetivos que se pretenden alcanzar con el presente trabajo y la metodología empleada para la consecución de los mismos, en el presente capítulo vamos a hacer una referencia al contenido de cada uno de los trabajos presentados. Por un lado se pretende establecer explicar en que medida cada uno de los artículos puede contribuir al logro de los objetivos propuestos y con ello al objetivo principal de la presente línea de investigación, y por otro lado, plantear las posibles dudas y/o limitaciones que nos hemos encontrado a lo largo de su desarrollo.

Tal y como se puede observar en la figura 3-1, los diferentes trabajos individuales realizados y que conducen a la elaboración del presente trabajo de tesis, han sido llevados a cabo teniendo en cuenta las diferentes necesidades que se presentan en cada momento para responder a los requerimientos del desarrollo de un software denominado *Mulino Decision Support System* (mDSS).

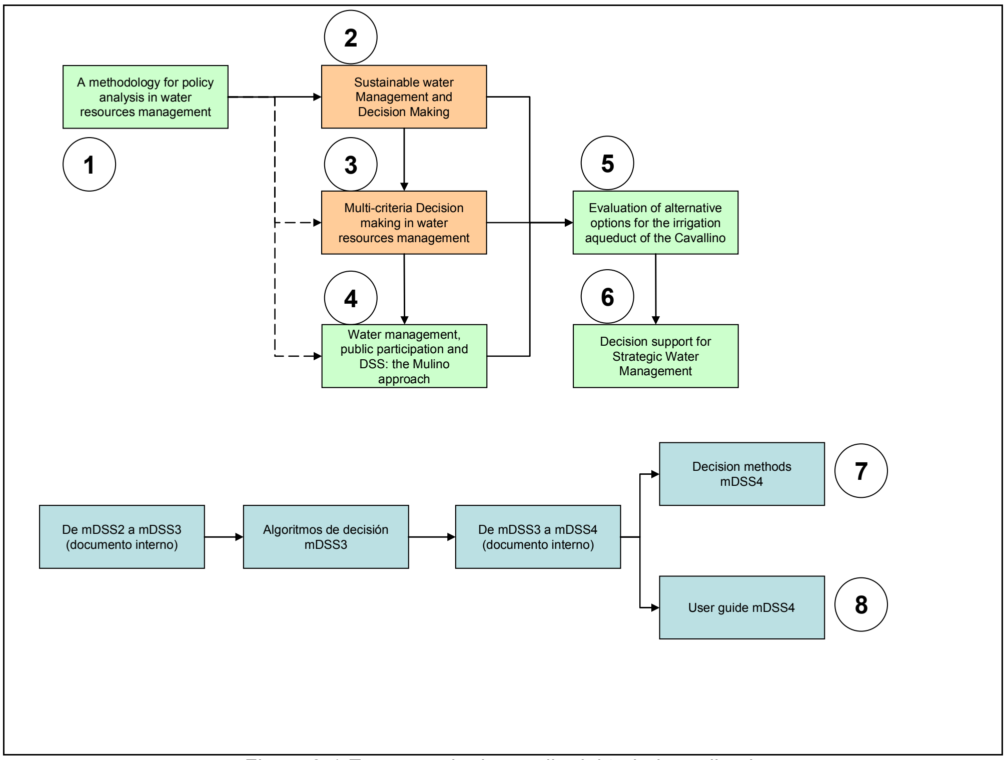

Figura 3-1 Esquema de desarrollo del trabajo realizado

Tal y como se ha indicado previamente en la metodología, contemporáneamente a la realización de estos artículos, capítulos y comunicaciones presentadas, se ha realizado un trabajo de desarrollo del mDSS. El trabajo fundamental ha consistido en la evolución desde una versión 2 a una 4 versión bastante más evolucionada y que incorpora muchas más funcionalidades derivadas de los resultados de investigación de cada uno de los capítulos.

Pasaremos a continuación a realizar un breve comentario de cada uno de los trabajos presentados.

1. ***A methodology for policy analysis in water resources management***

En este trabajo que se presenta en el apartado 1 del capítulo 4, y que se relaciona con el primer objetivo específico descrito en el apartado anterior de definir un enfoque metodológico, se pretende contrastar la utilización de un marco conceptual, denominado DPSIR como punto de partida en la estructuración de problemas de tipo ambiental, y en particular las políticas de aguas.

El primer paso para abordar este trabajo ha sido realizar un análisis de la complejidad que plantea la gestión y la planificación integrada del agua, en los cuales los decisores son las administraciones públicas. Inicialmente teniendo en cuenta la propia complejidad natural que este tipo de problemas ambientales suponen, y al que se le añade la complejidad administrativa que actualmente la toma de decisiones en este campo conlleva. La existencia de competencias a diferentes niveles de administración pública en la gestión del agua y los posibles conflictos que puedan surgir, han de ser elementos tenidos en cuenta a la hora de establecer una metodología de análisis.

A continuación, y basándose en el trabajo realizado por Bogardi para Naciones Unidas se propone el concepto de gestión integrada del agua como un problema de decisión multicriterio que permita la estructuración, modelización y elaboración de recomendaciones para el desarrollo de políticas públicas de gestión de aguas que a la vez sirva de instrumento de discusión y resolución de conflictos entre los diferentes niveles administrativos.

Por último se propone el uso del DPSIR, ampliamente utilizado a nivel público en materia ambiental, como elemento básico de referencia en la fase de estructuración de problemas desde la perspectiva multicriterio.

Este enfoque metodológico ha sido implantado en el desarrollo del sistema de ayuda a la decisión mDSS, en la denominada fase conceptual. Si bien el planteamiento inicial proponía una visión más modelizadora del problema decisional (mDSS2), la aportación que se realiza a partir de la realización del presente trabajo es un diseño mucho más visual e intuitivo que acompañe a este enfoque eminentemente holístico. Así pues, se diseña una nueva gráfica en el interfaz que permita tener una visión global de las cadenas DPSIR.

Aún cuando este enfoque y su implementación operativa creemos pueden suponer un avance en la estructuración de problemas relacionados con la gestión del agua, consideramos que existen todavía muchas posibilidades de mejora. Ejemplo de ello es que el marco conceptual propuesto (DPSIR), no permite la incorporación al proceso de estructuración de otros elementos diferentes a los existentes y supone siempre una consideración antrópica como fuerza motriz de los problemas derivados de la gestión del agua. Esto supone además una limitación importante, ya que no permite de forma directa la inclusión en el análisis de aspectos como la interrelación entre políticas públicas y sus posibles efectos.

Este artículo fue presentado en la *European Summer School in Resources and Environmental Economics* en septiembre de 2003. La presentación del trabajo bajo la supervisión de profesores de distintas universidades como los profesores Anthony Heyes (University of London), Per Fredriksson (Southern Methodist University, Dallas), Jason Shogren (University of Wyoming), Toke Aidt, (Cambridge University) y el profesor John List (University of Maryland) y las colaboraciones de los distintos participantes, permiten confrontar los objetivos propuestos ante la comunidad científica.

2. *Sustainable water management and decision making*

A raíz del este primer trabajo y las aportaciones al trabajo previo, en el presente apartado 2 del capítulo 4, se pretende profundizar más en el primer objetivo de objetivo de definir un enfoque metodológico y así como de dar respuesta al segundo objetivo que nos hemos propuesto y que supone establecer un marco de referencia conceptual de la gestión sostenible del agua.

En primer lugar se plantea la necesidad de realizar una revisión del concepto de desarrollo sostenible y sus implicaciones en la gestión del agua. Para ello se hace un repaso histórico de la evolución del concepto de desarrollo sostenible a lo largo de las últimas décadas tanto a nivel mundial como a nivel europeo en cuyo caso ha supuesto el antecedente fundamental que da lugar al desarrollo de la Directiva 2000/60/CE del Parlamento Europeo y del Consejo de 23 de octubre de 2000 por la que se establece un marco comunitario de actuación en el ámbito de la política de aguas. Una vez hecha esta revisión histórica, en analizan las implicaciones que tiene el concepto de gestión sostenible del agua a nivel de toma de decisiones y en particular se resalta la necesidad de integrar los aspectos ambientales, económicos y sociales bajo una perspectiva de participación pública. Se analiza a su vez la dificultad que supone el concepto de análisis integrado y se pone de manifiesto la necesidad de desarrollar metodologías e instrumentos que favorezcan dicha integración.

A continuación, se analizan diferentes los diferentes conceptos que son relevantes para la puesta en práctica del concepto de sostenibilidad y la relación que existe entre ellos, a saber: indicadores, marcos conceptuales, herramientas de análisis y evaluación. Por este orden se analiza el papel del uso de indicadores como base para el control y medida del progreso hacia la sostenibilidad teniendo en cuenta las cinco categorías de indicadores establecidas por la Agencia Europea de Medio Ambiente en base al propósito de los mismos. Se hace también una revisión de los marcos conceptuales como mecanismo que permita organizar la información proporcionada por los indicadores y dar así un significado de las interrelaciones existentes entre ellos. A continuación se definen los conceptos de métodos y herramientas de análisis como la forma de sintetizar la información generada con objeto de mejorar los procesos decisionales y se destaca la importancia de los sistemas de información geográfica como instrumentos de análisis así como la necesidad de incorporar información procedente del análisis de los actores implicados. Por último se describe la importancia de los métodos y herramientas de evaluación como último paso previo para la toma de decisiones sostenibles.

Para finalizar este capítulo, y en base a las consideraciones realizadas en los apartados anteriores se propone un enfoque metodológico que permita la gestión integrada del agua desde la perspectiva del desarrollo sostenible. Dicho enfoque servirá de referente para el posterior desarrollo del software mDSS.

Este capítulo, si bien entendemos que puede considerarse una buena aproximación conceptual al contexto de desarrollo sostenible y a los métodos y herramientas que permiten su análisis y evaluación, creemos que es necesaria un estudio más profundo de las potencialidades y limitaciones y su repercusión en el proceso decisional. La elección del marco conceptual DPSIR obedece más a una cuestión de adaptación a la estructura de indicadores, métodos e instrumentos de análisis existentes que a una mejora de los mismos. Así pues no se ha podido evaluar la idoneidad de otro tipo de indicadores, metodologías e instrumentos citados.

Este trabajo se publica en un bloque referido a la ayuda a la toma de decisiones dentro del libro dedicado a la gestión sostenible del agua y editado por Edward Elgar. Para la edición de este libro se cuenta con editores de reconocido prestigio en este ámbito y se establece un proceso de revisión entre los diferentes autores, siendo los editores son los profesores Carlo Giupponi (Università di Milano), Anthony Jakeman (The Australian National University), Derek Karssenberg (Utrecht University) y Matt P. Hare (Seecon Deutchland GMBH).

3. Multi-criteria decision making in water resources management

El trabajo que se desarrolla en el apartado 3 del capítulo 4, trata de abordar el cuarto objetivo de desarrollar una herramienta que permita la integración de los aspectos relevantes de la gestión del agua en el ámbito de la ayuda a la decisión multicriterio. Este objetivo hace necesario una revisión amplia y profunda de la literatura existente ya que en cierta medida es uno de los ejes fundamentales de esta investigación.

Para ello se realiza en primer lugar una breve descripción de la terminología y los conceptos básicos relacionados con la toma de decisiones. Se toma como referencia y punto de partida la definición establecida por Belton y Stewart (2002) teniendo en cuenta que se ha usado el término toma de decisiones multicriterio, como un paraguas bajo el cual se engloban términos como “multi-atributo”, “multi-criterio”, “multi-objetivo” o “multi-dimensional”. A partir de aquí y teniendo en cuenta las diferencias de terminología citada se hace un repaso a los métodos multicriterio más populares, se identifican dos tipos fundamentales de problemas que para nuestro análisis pueden clasificarse en dos categorías: problemas de decisión multiobjetivo y multi-atributo. Se propone a continuación una comparación conceptual de ambas categorías y una breve definición del enfoque de cada una de ellas.

Por último es destacable señalar la revisión que consideramos bastante exhaustivo en la que se presenta el uso de la metodología multicriterio para la ayuda a la toma de decisiones en el ámbito de la gestión de aguas aplicada en diferentes contextos, número de decisores y tipología de problemas.

La revisión de la literatura, y en especial la de los artículos que hacen referencia a la gestión del agua, nos han de permitir en cierto modo tratar de identificar las bases para escoger la metodología más adecuada para ser integrada en nuestro enfoque, basado en problemas de carácter discreto.

En cualquier caso, dicha revisión no ha podido ser lo exhaustiva que hubiésemos deseado. La complejidad de los problemas y ciertas premisas de partida hace difícil que toda la información que deseábamos analizar estuviese disponible en los artículos publicados por lo que hubiese aportado mayor relevancia un contacto directo con los autores. Por otro lado, la revisión de casos de estudio no nos ha podido revelar el papel de la participación pública en dichos contextos decisionales y en que medida el uso de las diferentes técnicas se adapta a este requerimiento actual.

Sería interesante también analizar las ventajas y desventajas que resultan de la aplicación de diferentes metodologías sobre casos similares.

Al igual que en el apartado 2 del capítulo 4, este trabajo se publica en el mismo bloque dentro del libro dedicado a la gestión sostenible del agua y editado por Edward Elgar.

4. *Water Management, Public Participation and Decision Support Systems: the MULINO Approach*

A partir del trabajo realizado en el apartado 3 del capítulo 4 y siguiendo la línea de investigación desarrollada en la Fundación *Eni Enrico Mattei*, se destaca la necesidad de incluir en la metodología presentada en la que se basa el software, un apartado específico relacionado con la participación pública.

Con el trabajo presentado en el apartado 4 se pretende abordar el tercero de los objetivos planteados previamente. En primer lugar se hace referencia a la necesidad de incluir la participación pública en el proceso de toma de decisiones relacionadas con la gestión del agua tal y como establece la Directiva Marco de Aguas en su artículo 14, con objeto de hacer el proceso de toma de decisiones en este ámbito más transparente y comprensible.

Se analiza a continuación de forma más detallada el papel que juega la participación pública en la gestión del agua y se ponen de manifiesto las razones que hacen necesaria su inclusión en cualquier metodología que se desarrollo en este campo y las ventajas y desventajas que supone. Una vez que la importancia de la participación pública es reconocida, el trabajo trata de profundizar en la integración de este tipo de información en el proceso decisional y en las diferentes formas en las que se ha realizado en diferentes sistemas de ayuda a la decisión.

A continuación se expone el papel de la participación pública en enfoque metodológico propuesto en el capítulo anterior y en que medida afecta a la estructura y empleo de indicadores, marcos conceptuales, herramientas de análisis y de evaluación.

Aunque el enfoque presentado en este trabajo constata la necesidad de incorporar la participación pública en el proceso de gestión integrada del agua y propone su implicación en base a la metodología propuesta, no se ha realiza un estudio preciso del concepto de participación pública. En este sentido, pueden considerarse que los diferentes niveles de participación pública que van de la simple información a una participación activa suponen un tratamiento e implicaciones metodológicas completamente diferentes. Por otro lado tampoco se ha establecido una metodología precisa para la puesta en práctica de la participación pública en base a las diferentes técnicas existentes.

Este trabajo ha sido presentado en el congreso de la *International Environmental Modelling and Software Society* en Osnabruck (Alemania) cuyo proceso de aceptación incluye una revisión por el editor, un miembro de la comisión editorial y dos referentes anónimos. A raíz de este artículo y de las críticas y comentarios obtenidos en el congreso, se incorporan nuevas utilidades en el software, entre ellas el modelo que permite la comparación y análisis de los diferentes puntos de vista de los actores involucrados en el proceso.

5. *Evaluation of alternative options for the irrigation aqueduct of the Cavallino Peninsula using the MULINO approach.*

Este artículo que se presenta en el apartado 5 del capítulo 4, tratará de resolver el quinto objetivo que nos habíamos planteado. Tal y como ya se ha indicado previamente, la filosofía que se ha seguido en todo momento en esta investigación ha sido la de tratar de resolver las distancias existentes entre el mundo científico y el mundo que podemos denominar como real. El desarrollo de una herramienta y una metodología de estas características no podrían estar completas sin un trabajo de campo que nos permitiera determinar los elementos fundamentales de un proceso de decisión de estas características.

Se trata pues, de un trabajo empírico, resultado de la aplicación de la metodología y la herramienta desarrollada a un problema de gestión de regadíos en la península del *Cavallino* en el noreste de Italia.

En primer lugar se hace una introducción al caso de estudio y las motivaciones que han llevado a la necesidad de tomar una importante decisión en materia de gestión de aguas. El Consorcio de Saneamiento del Bajo Piave, que es el ente público encargado de gestionar el agua para uso de riego en la zona, ha de afrontar una ley (D.L. 29/3/1995 n. 96) que obliga a la clausura de los pozos artesanos en la zona para ser sustituidos por un nuevo sistema de riego, lo que da lugar a un proyecto para el cual se desarrolla el consiguiente estudio de impacto ambiental.

A continuación se presenta el enfoque que se va a seguir para la realización del caso de estudio siguiendo la metodología desarrollada y un sistema de análisis de redes sociales que permita la integración de la información de todos los actores que se ven afectados por el presente proyecto. La participación pública en este caso de estudio se ha realizado fundamentalmente en la fase de elección y evaluación para lo que se diseñan y se llevan a cabo diferentes actividades tales como la entrevista personal con los afectados, reuniones conjuntas y seminarios informativos.

En cuanto a las limitaciones del estudio cabe destacar el hecho de que, si bien la colaboración realizado ha sido estrecha a lo largo del desarrollo del proyecto, no se ha participado en la fase inicial de desarrollo del mismo. Ello condiciona el factor de participación pública en la generación de alternativas y la consideración de otros factores que pudieran ser relevantes en el proceso decisional. Por otro lado no se ha entrado a valorar la idoneidad del uso del análisis de redes sociales propuesto con el uso del software AGNA (*Applied Graph & Network Analysis*) por lo que no ha quedado suficientemente justificado su inclusión. Su uso se debe a una aportación del socio portugués del proyecto Mulino. Tampoco se ha establecido un procedimiento estándar de aplicación de la participación pública .

El artículo se ha presentado de forma resumida en la revista *Italian Journal of Agronomy.* Dos de los autores son miembros del proyecto de investigación en el que se enmarca este trabajo de investigación y cabe destacar el tercero, D. Lorenzo Furlan que es el responsable técnico de la asociación. A raíz de este artículo se han realizado varias presentaciones en distintos foros internacionales así como la participación en grupos de trabajo de la Comisión Europea para la aplicación de la Directiva Marco de Aguas. Los resultados han sido utilizados para presentar oficialmente dicho proyecto para su evaluación por la Autoridad Regional del Veneto en la comisión de evaluación ambiental.

6. *Decision Support for Strategic Water Management: mDSS in the Large Dam Context*

Al igual que el apartado anterior, el presente trabajo, que se presenta en el apartado 6 del capítulo 4, trata de afrontar el quinto objetivo de probar la herramienta en un caso de estudio. a través de una colaboración con Elke Petersson y Carlo Giupponi, fruto del trabajo desarrollado en la Fundación *Eni Enrico Mattei*. El objetivo fundamental de este artículo era tratar de probar la potencialidad de la metodología propuesta no sólo en el ámbito de aplicación de la Directiva Marco del Agua sino teniendo en cuenta las directrices establecidas por la Comisión Mundial de Presas (*World Commission of Dams)* para la realización de futuros proyectos de construcción de embalses.

En este caso se trata de analizar de una forma sistemática y a posteriori, las motivaciones que guiaron el proceso de decisión de la construcción de la presa de Ceyhan Aslantas (Turquía) ya ejecutado en los años 70.

En primer lugar se describen las motivaciones que han llevado a realizar el presente trabajo y en que medida la aplicación de una metodología como la propuesta podría contribuir a las premisas de equidad, sostenibilidad, eficiencia y participación pública propuestas por la Comisión Mundial de Presas. De igual forma se plantea el uso de la metodología como un medio para investigar el efecto de la incertidumbre en los resultados obtenidos y en los juicios de valor que han guiado la decisión.

Seguidamente se realiza una breve presentación de la metodología y del caso de estudio, para a continuación hacer un estudio de potencialidad en el caso de estudio de cada una de las tres fases principales de proceso decisional establecido en la metodología que subyace al mDSS.

En este caso la aportación fundamental que se realiza es el desarrollo del árbol jerárquico de decisión y los criterios decisionales así como ciertas consideraciones en el análisis de sostenibilidad. Los resultados de la utilización de estos aspectos han sido incorporados en la última versión del software mDSS, una vez ya finalizado el proyecto.

Si bien se puede decir que el caso de estudio ha sido realizado de una forma sistemática, el hecho de tratarse de una decisión tomada en los años 70, no ha permitido tener un contacto directo con los que en su día fueron los responsables del proyecto. De igual modo, la información utilizada posee las limitaciones propias de los requerimientos de información relativos al periodo en cuestión y no se puede determinar el grado de fiabilidad de los mismos. Sería necesario también haber realizado un estudio más en profundidad del contexto económico, social y político de la Turquía de los años 70 para permitir una contextualización más adecuada del problema.

Este trabajo se presenta en la revista *Water International* que depende de la *International Water Resources Association*.

7 y 8. *mDSS4 Decision Methods* y *mDSS4 User Guide*

Los dos siguientes trabajos que se presentan en el apartado 7 y 8 del capítulo 4, recogen en cierta medida todos los objetivos que se han afrontado a lo largo de los capítulos anteriores y que se sintetizan en el objetivo principal de este trabajo de investigación que es desarrollar, evaluar e implementar un sistema de ayuda a la decisión. La guía de usuario pretende orientar al usuario potencial en el modo que puede aplicar las diferentes propuestas metodológicas disponibles en el software.

En el primero de ellos se describe el diseño funcional del mDSS4, como un sistema de ayuda a la decisión que permite el apoyo para la implementación de la Directiva Marco del Agua en especial en el desarrollo de los Planes de Cuenca. En el capítulo se explica en detalle como se ha implementado el análisis multicriterio y se proponen diferentes ejemplos para mostrar como funcionan los distintos métodos utilizados.

En primer lugar se da una descripción de la estructura genérica de la metodología NETSYMOD. Esta metodología supone una evolución de la que hasta el momento se había desarrollado para el proyecto Mulino. Una vez finalizado el proyecto en el año

2003, el grupo de trabajo prosigue su investigación colaborando en otros proyectos de investigación europeos en los que el uso de mDSS3 ha derivado en esta nueva versión mDSS4.
A continuación se definen las etapas básicas del análisis multicriterio como ha sido implementado en el mDSS una vez realizada la fase de estructuración del problema. y se describen la metodología empleada que va desde la generación de una matriz de análisis y estandarización hasta la modelización de las funciones de valor que expresan las preferencias de los usuarios del decisor o usuario del software. Así mismo se propone a continuación breve explicación del modo en que se modelizar los criterios de comparación de las alternativas de elección y a su vez se describen los diferentes métodos de agregación que se incluyen en el software: *simple additive weighting, order weighing average*, *TOPSIS* (Hwang y Yoon,1981) y *ELECTRE (Roy,1985)*.

Siguiendo la estructura planteada al inicio del capítulo, el paso siguiente en ser descrito es el análisis de sensibilidad que permita determinar la robustez del proceso decisional. El software permite la utilización del método de análisis del criterio más crítico y una representación visual a través del diagrama Tornado.

Por último se describe el modo en que se tiene en cuenta la agregación de preferencias en el proceso de toma de decisiones en grupo. Tal como se indica el software permite la consideración de los puntos de vista de los diferentes actores involucrados en el proceso y un análisis comparativo de los mismos para detectar por un lado las divergencias que pudieran existir y proponer la forma de obtener una solución de compromiso.

Si bien el trabajo representa un estudio detallado de los métodos empleados existen algunas consideraciones que deberían de tenerse en cuenta y que deberían incorporarse en un posterior trabajo. Ha de tenerse en cuenta que los procedimientos han sido descritos con objeto de hacer más accesible su comprensión por parte de aquellos que no tienen unos conocimientos muy avanzados en la materia.

CAPÍTULO 4

TRABAJOS PRESENTADOS

4. TRABAJOS PRESENTADOS

En el presente capítulo se presentan los distintos trabajos realizados en la línea de investigación que conforman esta Tesis Doctoral.

"*A methodology for policy analysis in water resources management"*, Jacobo Feás. EAERE – FEEM- VIU European Summer School, Venecia (Italia), junio 2003.

"Sustainable water management and decision making", Carlo Giupponi, Anita Fassio, Jacobo Feás y Jaroslav Mysiak Sustainable Management of Water Resources: an integrated approach., Giupponi-Jakeman-Derek Kasserberg Editors, Edward Elgar Publishing. 2006. ISBN-10 1 84542 745 9.

"Multi-criteria decision making in Water Resources Management", Jacobo Feás y Paolo Rosato Sustainable Management of Water Resources: an integrated approach., Giupponi-Jakeman-Derek Kasserberg Editors, Edward Elgar Publishing.2006. ISBN-10 1 84542 745 9.

"Water management, public participation and decision Support systems: the mulino approach", Jacobo Feás, Carlo Giupponi. Y Paolo Rosato, Complexity and Integrated Resources Management. Transactions of the 2nd Biennial Meeting of the iEMSs. Edited by Claudia Pahl-Wostl, Sonja Schmidt, Andrea E. Rizzoli, and Anthony J. Jakeman. ISBN 88-900787-1-5

"Evaluation of alternative options for the irrigation aqueduct of the Cavallino Peninsula using the MULINO approach". Carlo Giupponi, Jacobo Feás, Adrian Stanica y Lorenzo Furlan. Italian Journal of Agronomy. 2006. ISSN 1125-4718

"Decision support for strategic water management: mDSS in the large dam context". Elke Petersson, Carlo Giupponi y Jacobo Feás, Water International. Junio. 2007. ISSN 0250-8060.

mDSS Decision Methods. Carlo Giupponi, Jacobo Feás y Jaroslav Mysiak. http://www.netsymod.eu/mdss/userguide.pdf

mDSS User Guide. Carlo Giupponi, Jacobo Feás y Jaroslav Mysiak.
http://www.netsymod.eu/mdss/decmeth.pdf

4.1 A METHODOLOGY FOR POLICY ANALYSIS IN WATER RESOURCES

"*A methodology for policy analysis in water resources management*,., EAERE – FEEM- VIU European Summer School, Venecia (Italia), junio 2003

A methodology for policy analysis in water resources management

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Abstract

This paper illustrates the adoption of the DPSIR conceptual framework in the structuring phase in a Multicriteria Analysis (MCA) concerning the evaluation of water policies. In this paper we propose part of a methodology to facilitate the decision making process in water resources management under the perspective of the WFD, that has been developed in the MULINO project.

Keywords: Water Policy, DPSIR, Multicriteria Analysis, Water Resources Management.

Introduction

At the end of 2000, the European Commission published the Directive 2000/60/CE establishing a framework for Community action in the field of water policy that may be considered as the "most significant piece of European water legislation for over twenty years" (Foster et al., 2000). This new legislation through 26 articles provides for achieving the sustainable management of water resources under an integrated approach.

The new challenges posed to the people responsible for the management of water resources across the European Union include the coordination of existing national policies with the stipulations of the WFD. It has been designed to resolve some of the more persistent problems that obstruct the achievement of the EU environmental objectives, and can be interpreted as an attempt at

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establishing a coherent legislative framework for the protection and improvement of the water environment within the context of achieving sustainable development.

Under the WFD, we try to highlight in this paper the difficulties that policy–makers find when they have to deal with decision related to the environmental field and in particular with water management. We propose the use of multiple criteria decision aid methods based on an environmental assessment tool called DPSIR framework as a methodology to facilitate the public environmental planning and decision process in a context of sustainable and integrated water resources planning and management.

The complexity of Integrated Water Resources Planning and Management

Integrated Water Resources Planning and Management is considered a very complex issue since it is usually solved by the multisectoral-interdisciplinary hierarchical decomposition approaches. In general, integrated management indicates the consideration of water, social, socio-economic, economic and environmental issues.

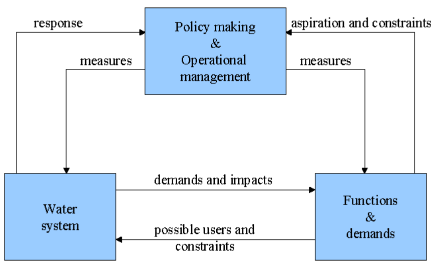

Figure 1: concept of integrated water resources management (Bogardi, 1994)

But it's also necessary consider, like in environmental planning in general that to complicate the process further, there are a large numbers of decision-makers involved in the process with conflicting preferences and value judgements (Lahdelma et al. 2000).

Decision problems concerning environmental and natural resources management are usually complex or even hyper-complex problems (Brans, 2002) A deep analysis and decision making process require a high background in environmental, economic and social disciplines The paradox here is that the scientific community is mostly working on very detailed and more narrow aspects whereas the managers require a holistic and ecosystemic approach, not necessarily at a high level of detail (Elliot, 2002). But the gap between those who analyse and those who decide, is not only in the knowledge but also in the aims and the way of thinking (Luiten 1999). For that reason, our objective proposing the present methodology is to link politic and science world providing a tool to facilitate the communication between them.

But the complexity goes further if we consider the administrative aspects of the environmental decisions. Any decision related with water resources management in Europe is undertaken within the framework of policy. But this policy framework could be established at various hierarchical administrative levels, starting from local authorities, regional and national governments, to European Union and another international levels.

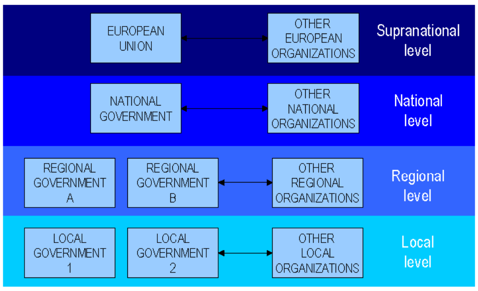

Figure 2: Structure of policy units

At this point, sometimes is not easy to develop policies with the agreement of all the policy units involved in the water resources management. When we are dealing with different levels of policies some conflicts may arise because the differences in objectives and goals pursued by the policy units. Decisions at national level could not satisfy the values and perceptions of the policy units at local level.

The last point to remark in this complex framework is the existing links between water policy and other related fields because decisions in water resources management affect, and are affected by other policy areas. So we cannot consider water policy as an isolated task, neither the development of policies in other areas without references to the water policy. Areas like environment, energy, industry, agriculture, tourism had an important role in the water resources management and water policy.

The purpose of the methodology proposed is to support the assessment of policy analysis in order to measure how a specific policy meets the objectives established by the policy units/actors. Also allows to identify the possible conflicts that may arise between and within different policy units helping to clarify the reasons of the discordances between them. Analysing these reasons we can set up the basis for a better understanding or possible paths to arrive at a compromise resolution of the conflicts.

The basis of this methodology is the Multicriteria Decision Analysis which principal objective is "help decision makers learn about the problem situation about their own and others values and judgements, and through organisation, synthesis and appropiate presentation of information to guide them in identifying, often through extensive discussion, a preferred course of action" (Belton et al, 2002).

Using Multicriteria methods in water resources management

Using Multicriteria methods we don't try to obtain the right answer when we have to decide between different sets of policy options, neither provide an objective analysis will relieve decision makers the responsibility of making difficult judgements. We try to make the subjective judgements explicit and the process by which they are taken into account transparent, which is very important when a large number of actors are involved in the decision process (Belton et al., 2002).

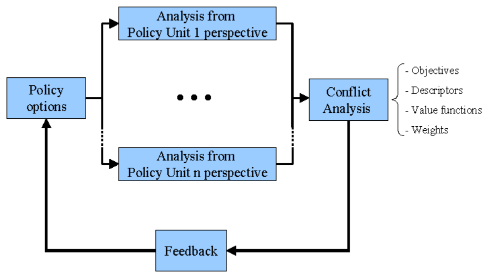

Figure 3: Conflicts between policy units

So the main idea is to show how to explore and evaluate the objectives, judgement values, constraints and impacts of a policy from a single actor/policy unit perspective and how to compare different options. This is based on a multicriteria model, which associates to each policy option an index of attractiveness, which depends on the impacts of the policy and on the subjective values of those who evaluate it. This index can be used to compare options with each other (policy unit/actor) or to assess the absolute attractiveness of a policy option.

There are a lot of MCDA approaches but in general terms, the MCDA methodology unfolds in a series of stages:

- Problem structuring, that is the analysis of the concerns of a unit and the selection of the descriptors to specify the impacts of policy options;
- Model building, which is the construction of the value index, which serves to state the attractiveness of a policy option for a policy unit.

- Elaboration of recommendation that is the substantive interpretation of the evaluation in terms of guiding the behaviour of the policy unit in the decision process.

The DPSIR framework to structuring the decision problem

The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill (Einstein, 1938).

The process of structuring a decision making process seems to be the most valuable and the essential part of the MCDA methodology. Moreover, all the MCDA methods are based in how the decision makers expresses the main concerns about a problem, so if the problem is not well defined, their preferences will not be constructed a robust way.

Most of the MCDA applications on water resources management start their analysis adopting a stance of "given the problem" and are more focused on evaluation stage and the elaboration of recommendations.

In the last decades, a large set of evaluation techniques had been developed, but in our opinion the most difficult and important matter in this context is to identify the fundamental concerns of the decision process: goals, constraints, uncertainties, actors involved, alternatives…In this paper we are mainly focused on the structuring stage of the decision process on the idea that more time and effort should be spent on the phase of structuring a decision making problem, as this step might have consequences throughout the rest of the decision process[1].

Following the methodology proposed by Bana e Costa and Beinat in the DTCS project, we can define concern as any aspect within a specific context that

[1] The hole methodology is been developed under the MULINO project through the production of a decision support system called Mulino DSS (mDSS).

policy actors consider relevant for evaluating the attractiveness of policy actions. This definition includes both objectives of policy units/actors involved in the decision process, and the characteristics (or attributes) of policy actions. These concerns may differ between the different policy units involved or even between different actors within the same policy unit

But the task to identify these main concerns (both stated objectives and active characteristics) for each policy is not easy under this complex framework. The identification of this set of indicators is a prerequisite to represent the main concerns assessing and reporting the state of the environment and its evolution as affected by human activity But also is necessary a definition of a functional scheme to describe cause-effect linking the state of the various –ecological, economic, social, technological– indicators..

The OECD has argued that a successful indicator should:

- Reduce the number of measures which normally would be required for an exact presentation of a situation; and
- Simplify the process of communication to managers, stakeholders and communities.

In short, indicators should represent dynamic parts of an overall portrait that is understandable and compelling to its intended user community. They should be part of a process to minimize the number of individual variables and data points while maintaining a sufficient level of critical understanding to those responsible for or interested in coastal systems (Bowen et al, 2003).

But a simple set of indicators not satisfy the holistic perspective that's needed when the decision makers need to represent their point of view, because of their probably poor background of this technical aspects.

Relevant examples available to explore these issues and to support the structuring phase in this field are the PSR scheme (Pressure - State - Response), adopted by the Organisation for Economic Co-operation and Development (OECD, 1994), and the DSR (Driving force - State - Response) of the UN Commission on Sustainable Development (UN, 1997). More recently the DPSIR framework (Driving Force - Pressure - State - Impact - State - Response), was proposed by the European Environmental Agency (EEA, 1999) and adopted by many national and European institutions, EEA and Eurostat among other

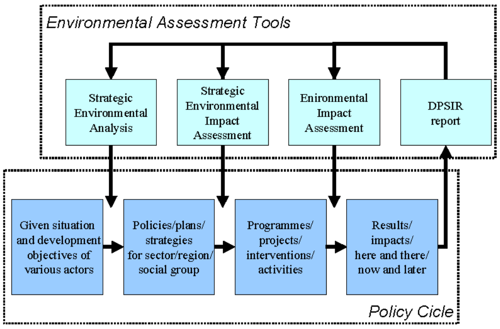

Figure 4:Policy cycle and environmental assessment tools

The DPSIR framework was originally developed by the EEA for environmental reporting purposes, as result of environmental monitoring, on different environmental assessment tools like Environmental Impact Assessment (figure 4), and structures the description of the environmental problems, by formalising the relationships between various sectors of human activity and the environment as causal chains of links.

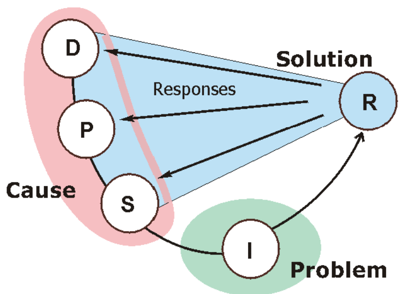

Figure 5: Decision Making withing the DPSIR framework

The environmental management process under the DPSIR framework, may thus be described as a feedback loop controlling a cycle consisting of five stages (figure 5).

- ***Driving forces*** are the underlying causes, which lead to environmental pressures. Examples are the human demands for agricultural land, energy, industry, transport and housing.
- These driving forces lead to ***Pressures*** on the environment, for example the exploitation of resources (land, water, minerals, fuels, etc.) and the emission of pollution.
- The pressures in turn affect the ***State*** of the environment. This refers to the quality of the various environmental media (air, soil, water, etc.) and their consequent ability to support the demands placed on them (for example, supporting human and non-human life, supplying resources, etc.).
- Changes in the state may have an ***Impact*** on human health, ecosystems, biodiversity, amenity value, financial value, etc. Impact may be expressed in terms of the level of environmental harm.
- The ***Responses*** demonstrate the efforts by society (e.g. politicians, decision makers) to solve the problems identified by the assessed impacts, e.g. policy measures, and planning actions.

DPSIR and decision making

Within this framework the task of decision makers (DMs) is therefore that of analysing the territorial system and assessing the acting Driving forces, their Pressures, the consequences on State variables and their ultimate Impact. From the assessment of Impacts they should determine appropriate Responses, in order to direct the final effect in the desired direction (a reduction in environmental harm). Therefore in a decisional context related to natural resource management, Impacts describe the existing problems arising from the change detected in State variables, which reduces the value (either in quantitative, economic, or qualitative terms) of the natural resource.

The level of the responses has to be related to the magnitude of the impacts. These different responses need different planning process and different DMs could be involved. The different planning levels could be policies, plans, programs (PPP) and projects, from macro to micro level and the DMs could be from European to local authorities.

In our particular analysis, we are focused at catchment's scale and for that reason, DMs are not able to propose responses at driving forces level with macro/sector policies. Main of their responses should be included in environmental policies (i.e. regional environmental policies) at pressure level or with some specific projects at state level. In any case, whatever the response, DMs have to be coherent in the environmental planning process with policies, plans and programs established at a higher level (i.e. irrigation project coherent with regional environmental legislation, this one coherent with national legislation under the WFD perspective)

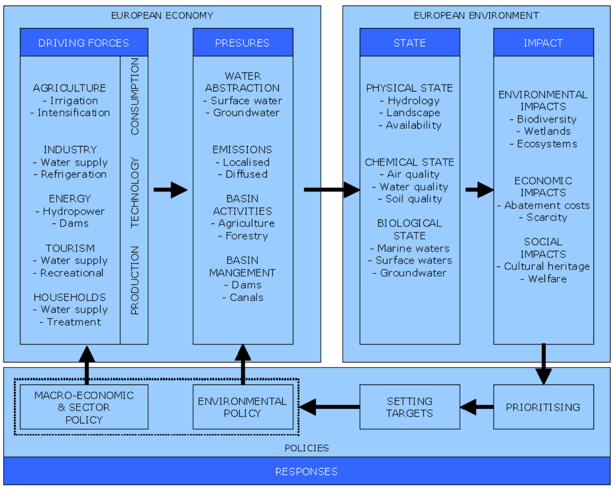

Figure : Integrated Environmental Assessment DPSIR framework applied to water management (adapted from NERI 1997)

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4.2 SUSTAINABLE WATER MANAGEMENT AND DECISION MAKING

“Sustainable water management and decision making”, Carlo Giupponi, Anita Fassio, Jacobo Feás y Jaroslav Mysiak Sustainable Management of Water Resources: an integrated approach., Giupponi-Jakeman-Derek Kasserberg Editors, Edward Elgar Publishing. 2006. ISBN-10 1 84542 745 9.

4. Sustainable Water Management and Decision Making

Carlo Giupponi, Anita Fassio, Jacobo Feás Vàzquez and Jaroslav Mysiak

4.1 DECISION MAKING IN WATER RESOURCES MANAGEMENT

Human society is always interacting with water, land and air, the natural resources of the earth. In particular:

> Water is essential to all life, all ecosystems and all human activity. Wisely used, water means harvests, health, prosperity and ecological abundance for the peoples and nations of the earth. Badly managed or out of control, water brings poverty, disease, floods, erosion, salinisation, waterlogging, silting, environmental degradation and human conflict.

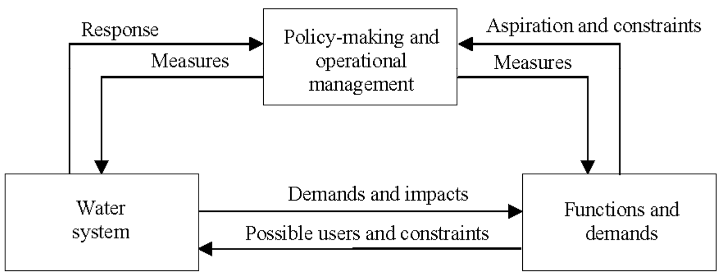
This quote from the World Water Council's Constitution (WWC, 1996) illustrates the essential role of water in our world. Water is a basic element for human survival; it is an important production factor in our economy, particularly in agriculture, and it is the habitat of a wide range of species.

As stated in the Introduction to this book, the IWRM approach, firmly bounded in the sustainability concept, stresses the need to view water resources in a holistic way, in which socioeconomics and environmental sciences should find integration. But water management must not rely only on robust and integrated scientific knowledge, it also needs to be supported by clear policy and regulatory frameworks and needs to be put in practice by means of adequate tools. The sustainable use of water resources, as defined in a number of policies and regulations, requires coherent and efficient tools that can assist decision making. For the purposes of this work, a useful definition of decision making which leaves enough room for interpretation, while remaining accurate, is the classical definition by Simon (1957): 'Decision making is the process of choice that leads to action'. Thus, decision making tools are all those instruments (methods, guidelines, software, etc.) that can facilitate the implementation of the IWRM principles, as described in policy documents and regulations.

One of the fundamental documents for framing IWRM in the broader concept of sustainable development is Agenda 21, signed by 178 governments at the Earth Summit in Rio de Janeiro in 1992. Chapter 8 of Agenda 21 aims at improving or restructuring the decision-making process so that consideration of socioeconomic and environmental issues is fully integrated and a broader range of public participation is assured. Integrated decision making was also discussed in Chapter 18 of Agenda 21 where the rationale for the sustainable development and the management of freshwater resources is clearly articulated. As already anticipated in the Introduction, the key elements of water resource management for sustainable development are integration (of disciplines, of approaches, and of tools), collaboration and participation (of all the actors involved), and the sharing of knowledge and information (Gijsbers, 2000).

Decision making should, therefore, involve the integration of different perspectives and objectives, and be prepared to manage trade-offs or priority setting between these objectives where necessary, by carefully assessing them in an informed and transparent manner, according to societal objectives and constraints (Van der Zaag 2001). IWRM again provides the reference for policy- and decision-making approaches providing joint consideration of the physical water system, and the societal functions and demands for water (Bogardi, 1994) (Figure 4.1).

Like environmental planning in general, IWRM is usually characterised by the involvement of numerous decision makers operating at different levels and the very large number of stakeholders with conflicting preferences and different value judgements (Lahdelma et al., 2000). This makes decision making in the context of IWRM a very complex issue because it requires a broad integration with other sectors such as environment, energy, industry, agriculture and tourism.



Source: Bogardi (1994).

Figure 4.1 Concepts of integrated water resources management

Adequate methodologies and tools therefore become necessary in order to measure how a specific policy meets the objectives established by the various actors, to identify and understand the possible conflicts that may arise between these actors and, finally, to design possible paths and courses of action to arrive at a sustainable solution.

The need for adequate methodologies and tools calls for a strong role to be played by science and research. The commitments made by the scientific community at the 2002 World Summit on Sustainable Development was in fact to make science more policy-relevant. Relevancy can be improved by placing more emphasis on social aspects of sustainability, by addressing the uncertainty of the scientific process by using common languages that are understandable to stakeholders, and by customising environmental assessments so that they are relevant to the local conditions and issues of a basin (ICSU, 2002).

As previously pointed out, environmental problems, and in particular those related to water resources, are usually very complex and therefore the decision-making process requires detailed background information from environmental, economic and social disciplines. Moreover, there is quite often a dramatic gap between those who analyse and provide disciplinary expertise and those who decide, not only in the knowledge but also in the aims, the way of thinking and the language (Luiten, 1999).

From the above it should be clear that bringing water resources management within the principles of sustainable development (SD) is a very complex issue, which can be supported by the scientific and methodological approaches of IWRM. The next section provides a concise presentation of such an approach in water resources management, and is based on the integration of information into adequate conceptual frameworks, analysis and assessment tools.

4.2 INFORMATION, CONCEPTUAL FRAMEWORKS, ANALYSIS AND ASSESSMENT TOOLS IN SUPPORT OF DECISION MAKING

Four major steps can be identified in the evaluation process of policies and decision making in terms of their contribution to sustainable development (Figure 4.2). The first step relates to the identification of a wide array of indicators and measures available for monitoring development and environmental change. These indicators can, and should, vary depending upon place and scale. The second step deals with conceptual frameworks, which provide powerful insight and organising qualities. The third involves specific forms of analysis that rely on indicators that are best selected through

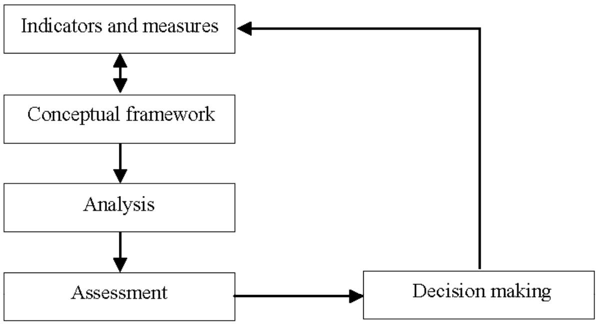


Figure 4.2 Four steps in knowledge and decision making for IWRM and sustainable development

the use of sound conceptual frameworks. Finally, all these steps contribute to a fourth one: sustainability assessment.

Throughout this chapter, each step will also be referred to as a 'tool' for assessing the effects and effectiveness of policy measures. Such tools are closely related to one another: indicators and measures are the pillars, as assessment and communication are their main function. Conceptual frameworks are ordering mechanisms that help organise indicators logically, for instance in cause-effect-response chains. Based on this information, analysis helps gain information and insight and contributes to the assessment of policy makers' decisions through specific and comprehensive decision support tools.

In an IWRM perspective, the above mentioned tools act as guiding instruments for decision making, involving the sustainable development, management, protection and use of freshwater resources. IWRM can be regarded as the vehicle that makes the general concept of sustainable development operational for the management of freshwater resources. Since it adopts an holistic approach, information is needed on the state of the economy, society and water resources, but their mutual relationship must be analysed, and impacts of proposed measures assessed, in order to make informed decisions.

4.2.1 Indicators

The 1992 Earth Summit recognised the important role that indicators can play in helping countries make informed decisions concerning SD. This recognition is articulated in Chapter 40 of Agenda 21 which calls on governments at the national level, as well as international, and non-government organisations, to develop and identify Indicators of Sustainable Development (ISDs) that can provide a solid basis for decision making at all levels.

ISDs can allow better communication and accessibility to information by bridging the gap between the producer and user of information, i.e. between the information available through scientific resources and the need of information for decision making (Boisvert et al., 1998). Indicators can provide crucial guidance for decision making in a variety of ways. They can translate physical and social science knowledge into manageable units of information that can facilitate the decision-making process. They can provide an early warning, sounding an alarm in time to prevent economic, social and environmental damage. They are important tools to communicate ideas, thoughts and values, and as one authority said, ‘We measure what we value, and value what we measure’ (UNCSD, 2001). A crucial role of ISDs is to provide a means of measuring, monitoring and reporting on progress towards sustainability, which is still an open problem both for the academia and the decision makers.

This process-oriented logic characterises SD: experts have to rely on information that allows them to judge on a regular basis whether or not the current evolution is to be considered as a contribution to ‘stay’ or to ‘get’ on a sustainable path. As such, SD requires constant feedback for evaluation and, as a consequence, decision making is also becoming more process-orientated (Bauler and Hecq, 2000).

Therefore, it becomes important to assess effects (ex-ante) and effectiveness (ex-post) of policy measures: effects imply that a policy has an impact on the outside world. The process of identifying effects is based upon scientific and social observation and analysis. Assessing effectiveness judges whether and how far the observed effects of a policy satisfy the explicit objectives, and this involves comparing intention with performance (EEA, 2001). In order to assess whether policies are working and to fine-tune them in order to reach the ultimate objective, feedback information for policy-makers and methodological approaches are needed.

Indicators are being classified in different ways, on the basis of the purpose they serve. The European Environmental Agency (EEA) distinguishes five categories of indicators (EEA, 1999). The first category (Descriptive indicators) answers the question: ‘How are pressures on the environment, and how is the quality of the environment, developing?’ Examples are indicators referred to in Chapter 3 for assessing water status. The second category includes EEAs Performance indicators that answer the follow-up question: ‘And is that relevant?’ The third category, which can be found in between the environment and the economy circle, are Eco-efficiency indicators, answering the question: 'Have we become more efficient in our economic processes?' The fourth category, Policy-effectiveness indicators, may provide answers to the question: 'What has been the effect of policy?', and clarify what the structural changes in the economy or in the production processes, and in the (environmental) decision making, have lead to. Finally, a fifth category of indicators (Total welfare indicators) is connected with the question: 'And are we on the whole better off?', which asks for a balance between economic, social and environmental progress.

Thinking in terms of questions to be answered, and trying to identify the proper questions for solving problems, helps in identifying the most suitable indicators. Formalising these questions helps to get a good balance in the indicator sets. Combining relevant indicators into a composite index reveals the available evidence in a much more convincing fashion than just using individual indicators (ICSU, 2002). With such purposes in mind, analytical frameworks structure a collection of indicators and communicate their application. These are discussed in the following paragraph.

4.2.2 Conceptual Frameworks

As stated in the previous paragraph, there should be a clear structure that communicates to policy-makers how each piece of information is related to the various policy processes. To achieve this, frameworks that structure a collection of indicators and communicate their application are being developed.

In general, different analytical levels require different frameworks. That is to say, depending on the detail of analysis and the purpose of the monitoring, different frameworks provide the proper support and help.

Three commonly used frameworks that can help 'think at the scales that matter and act at the levels that count' (Vasishth and Sloane, 2002) are listed below (Segnestam, 2002):

1. Input-Output-Outcome-Impact framework, which is used in the monitoring of the effectiveness of projects. Indicators are structured in terms of inputs, outputs and the overall project objectives;
2. UNCSD's framework based on environmental (or sustainable development) themes, in which indicators are organised according to Major Areas, Themes and Sub-themes 'to support policy-makers in their decision-making at a national level' (UNCSD, 2000);
3. Driving Force–Pressure–State–Impact–Response (DPSIR) framework for environmental reporting and monitoring at regional, national and international levels.

The DPSIR derives from other models developed in recent years: the PSR (Pressure–State–Response) model adopted by the Organisation for Economic Co-operation and Development (OECD, 1994) for its environmental performance reviews, and the DSR system (Drivers–State–Response) proposed by the Commission on Sustainable Development of the United Nations (UN, 1997). The models have been extended by EEA (EEA, 1999) to cover the causes (driving forces) and the impacts on the environment. The DPSIR framework is now also used by Eurostat for the organisation of the environmental statistics. The DPSIR framework will now be presented in detail for the purpose of the present work.

The DPSIR framework is widely used to structure indicators to allow for a holistic and multi-dimensional view of causal relationships. Within the DPSIR framework, indicators are used to assess the interaction between man and his environment. The integrated set of indicators is used by the decision maker to simplify the complex interlinking between human actions and the co-existing ecological, economic and social states. A graphical presentation of the scheme is reported in Figure 4.3: Driving forces (D) are the underlying causes which lead to environmental pressures (e.g. human demands for agricultural land, energy, industry, transport and housing); D's lead to Pressures (P) on the environment (e.g. the exploitation of resources deriving from human demands), which in turn affect the State (S) of the environment. This refers to the quality of the various environments (air, soil, water, etc.) and their consequent ability to support the demands placed on them (e.g. supporting human and non-human life, supplying resources, etc.). Changes of S may have an Impact (I) on human health, ecosystems, biodiversity, amenity value, financial value, etc., which may be expressed in terms of the level of environmental harm. Finally, Responses (R) demonstrate the efforts of society (e.g. politicians, decision makers) to solve the problems (e.g. policy

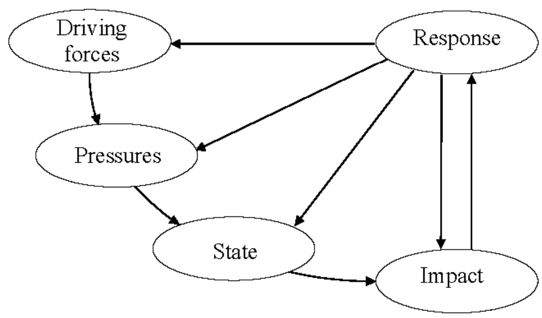
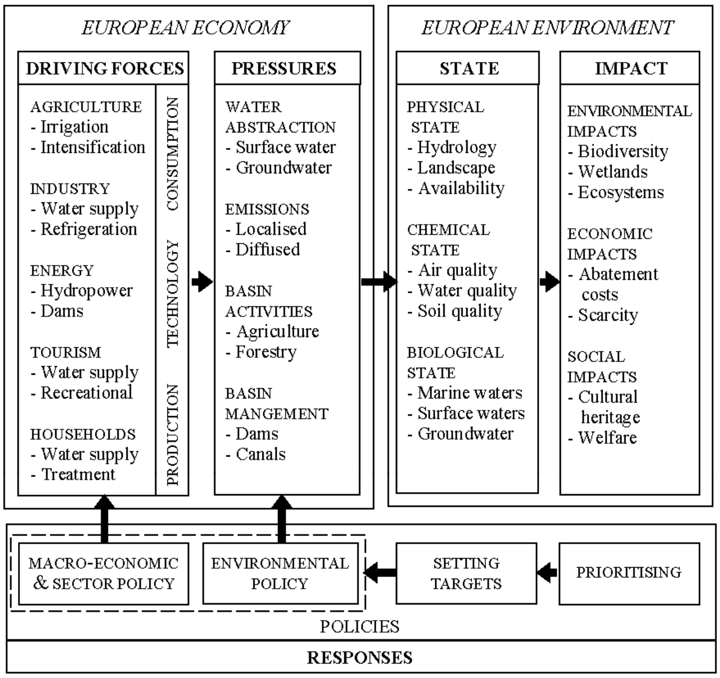


Figure 4.3 DPSIR framework

measures, planning, actions in general).

The framework is broadly accepted, and many countries find it useful for state of environment reporting. Core lists of environmental issues, and of relevant pressure–state–response indicators, have been developed by several organisations, building on initial work by the OECD. Italy, for example, publishes a national state of the environment report every two years using this framework, and is setting up a national monitoring system along the same lines. Several applications of the DPSIR approach have been proposed for the management of water resources, as in the example reported in Figure 4.4.

Conceptual frameworks may remarkably support a correct identification and use of indicators, first of all because they facilitate their categorisation and the identification of their mutual relationships. The EEA proposes the combination of the five categories of environmental indicators mentioned in



Source: Adapted from NERI, 1997.

Figure 4.4 DPSIR framework applied to water management paragraph 2.1 with the DPSIR framework (CEC, 2001):

> For problems that are in the beginning of their policy life cycle, that is, in the stage of problem identification, indicators on the state of the environment or on impacts play a major role. They will be mainly descriptive indicators, which identify alarming developments in the state of the environment. State indicators that may give rise to policy reactions can be those that describe the sudden decline of a particular species or of surface water quality. This function of state indicators is thus limited in time: as soon as a problem is recognised politically, the attention shifts to pressure and driving force indicators. In the next and longer stages of the policy cycle (formulation of policy responses, implementation of measures and control) performance indicators of the changes in driving forces and pressures, are the most used since policymakers focus on what they can influence. Eco-efficiency and policy effectiveness indicators are used to support and document the policy decisions and the level of acceptance and uptake of measures and also as tools to measuring the degree of meeting the stated objectives, with the involvement of stakeholders. Finally, in the control phase of the policy cycle, state indicators can be used again to monitor the recovery of the environment.

A framework for organizing the selection and development of indicators is essential. Nevertheless, it must be recognised that any framework, by itself, is an imperfect tool for organising and expressing the complexities and inter-relationships encompassed by SD. Ultimately, the choice of a framework and a core set of indicators must meet the needs and priorities of users, including national experts, civil society groups and decision makers. Indicators can therefore be considered as a basis for analysis, to be integrated into a wider assessment framework.

4.2.3 Analysis Methods and Tools

Analysis goes a step further, synthesising information to produce useful outcomes for improved decision making. Such technical tools help identify and apply existing knowledge to the challenges of SD, identifying gaps, and filling them through research. In this context, the main analytical methodologies are introduced.

When indicators have been selected and structured in a manner that facilitates their interpretation, analysis may follow. Analytical tools for such a purpose range from physical models, such as mathematical models (for example basin scale hydrologic modelling), and Geographical Information Systems, to various forms of economic analyses, such as cost benefit analysis, risk-benefit analysis, or multi-criteria analysis methods.

Modelling involves the process of using precise and typically mathematical descriptions of the system inputs, outputs and processes to simulate the present, past or future aspects of the system. Prediction and the ability to try out some different 'what if?' scenarios are essential to understand past and current developments, to anticipate the future and to evaluate policy strategies. Integrated Assessment Modelling (IAM) links the mathematical representations of different components of natural and social systems (see Jakeman et al., Chapter 10 and Letcher and Bromley, Chapter 11) at local, regional or global level. As Risbey et al. (1996) stress, IAM is more than just a model building exercise, it is also a 'methodology that can be used for gaining insight over an array of environmental problems spanning a wide variety of spatial and temporal scales'.

Today, powerful modelling tools with Geographical Information Systems (GIS) interfaces can be utilised to analyse the effect of possible measures such as changes in land use, water usage and water abstraction, or point and diffuse pollution. With respect to the construction and application of environmental models, a GIS can be used to import the spatial data needed for modelling, to manage the data in a database, process the data and to visualise the models' inputs and outputs. The most recent software technologies even merge GIS and modelling functionality using an environmental modelling language embedded in the GIS (see Karssenberg et al., Chapter 9).

Analyses of sustainability are not limited to physical sciences and economics. Dalal-Clayton in his resource book on *Sustainable Development Strategies* (Dalal-Clayton and Bass, 2002), draws attention to the importance of stakeholder analysis in SD: people, groups or institutions who have specific rights and interests in an issue that the strategy seeks to address. Such analysis, strongly supported by all the documents about SD, consists of the objective identification of stakeholders in the transition to SD, their interests, powers and relations. As a continuous process, it needs to involve those people who have an interest but might not otherwise have come forward. Mostert in Chapter 7 treats the topic of public participation and demonstrates its importance in IWRM.

From the above it becomes clear that the decision process in IWRM needs to analyse the multiple disciplinary viewpoints referring to the various objectives, judgement values and constraints. Several techniques are proposed in literature for supporting decision/policy-makers in exploring and evaluating their choices, and quite often they belong to the broad category of multi-criteria analysis methods (see Feás Vàzquez and Rosato, Chapter 5). These methods are based on a model, which associates an index of attractiveness to each policy/decision option, depending on its estimated impacts and on the subjective values of those who evaluate it. In general terms, MCA methodology unfolds into a series of stages:

1. Problem structuring, that is the analysis of the concerns of a unit and the selection of the indicators that measure the impacts of policy options;

2. Model building, which is the construction of the value index, which serves to state the attractiveness of a policy option for a policy unit;
3. Elaboration of recommendations that represent the interpretation of the evaluation in terms of guiding the behaviour of the policy unit in the decision process.

When dealing with integrated water management, the main problems generally arise at the beginning of the decision process because of the difficulty of having an overall perspective of the problem and a deep understanding of all the issues involved. The structuring of a decision-making process seems to be the most valuable and essential part of the MCA methodology, in that it can provide a useful basis for developing further the decision process by means of assessment methods and tools.

4.2.4 Assessment Methods and Tools

Ensuring the implementation of SD requires the further development and packaging of appropriate ‘tools’ that can aid project and programme development, and assist the setting of policy frameworks. Moreover, the evaluation of proposed policies or decisions in general may require tools integrating the various monitoring and analysis tasks. Therefore, conceptual frameworks providing adequate information in the form of indicators, combined with analytical tools to analyse cause-effect links and correlations, should be further integrated into assessment tools. The incorporation of appropriate instruments into an integrated tool is fundamental to the implementation of SD.

Assessments may guide, support, monitor and evaluate policies and decision making that seek actions supporting SD. Different assessment approaches and tools were developed in the past aimed at supporting the development and implementation of various typologies of actions, some of which are briefly introduced below.

Impact assessment is a planning approach that provides detailed documentation on environmental and social impacts, adverse effects and mitigation alternatives. It is a process to improve decision making and to ensure that the measures under consideration are environmentally and socially sound and sustainable. Impact assessment now includes a broad suite of different techniques, including environmental impact assessment (EIA), social impact assessment (SIA), cumulative effects assessment (CEA), environmental health impact assessment (EHIA), risk assessment, strategic environmental assessment (SEA) and biodiversity impact assessment (BIA) (Donelly et al., 1998).

Impact assessment relates to a process rather than a particular activity. It provides information on the environmental, social and economic effects of proposed activities and is a mechanism by which information can be presented clearly and systematically to decision makers. For these reasons impact assessment can provide the basis for a correct approach to the concept of sustainability assessment (SA), the fourth step in which the process for implementing IWRM culminates, as reported in Figure 4.2. According to the level and the scale at which SA is performed, two methodologies could be of particular interest: environmental impact assessment (EIA) and strategic environmental assessment (SEA). Within the context of impact assessment methodologies, EIA has conventionally been applied at a project level. It represents a limited response to the challenges of sustainable development (Dalal-Clayton and Bass, 2002). Within the context of EIA, Multi-criteria analysis methods help in selecting options based on objective functions including weighted goals of the decision maker, with explicit consideration of constraints and costs.

In an IWRM perspective, EIA plays a central role in acquiring information on the social and environmental implications – including water resources implications – of development programmes and projects, identifying the measures necessary to protect the resource and related ecosystems and then ensuring that such measures are implemented. The IWRM approach implies that sectoral developments are evaluated for possible impacts on the water resource and that such evaluations are considered when designing or prioritising development projects. EIAs are not only concerned with impacts on the natural environment but also with effects on the social environment. Hence, the EIA includes cross-sectoral integration of project developers, water managers, decision makers and the public, and provides a mechanism or tool to achieve this.

It is increasingly evident that many of the environmental problems associated with development projects arise from insufficient attention being given to environmental issues at higher levels of policy-making. SEA has thus emerged in the last decade as a more proactive, integrated approach that addresses the causes of unsustainable development, which were previously promoted by government macro-economic policies, investment, trade and development programmes, energy and transport plans, and so on (Dalal-Clayton and Bass, 2002) (Figure 4.5).

Sadler and Verheem (1996) have defined SEA as

> A systematic process for evaluating the environmental consequences of proposed policy, plan or programme initiatives in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision-making on par with economic and social considerations.

SEA is therefore a cross-sectoral tool (like EIA), relevant in the area of water resources management as well, that should be seen as a decision-aiding

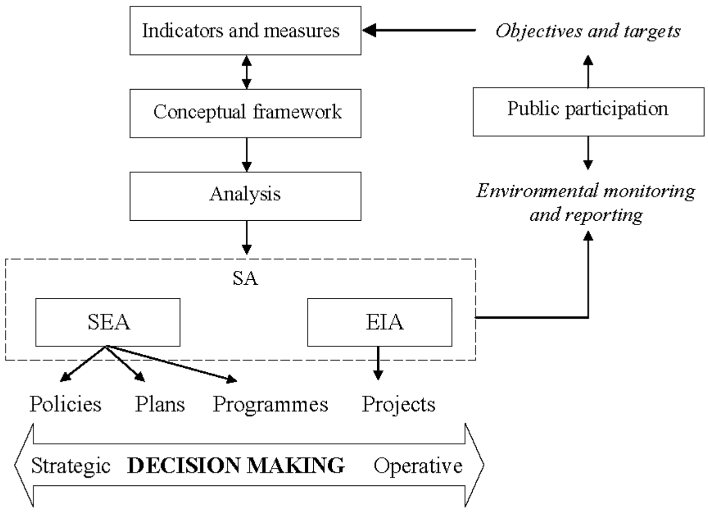


Figure 4.5 Sustainability assessment approaches within the context of the process of knowledge and decision making for IWRM and sustainable development

rather than a decision-making process; it is a flexible 'tool for forward planning' to be applied at various stages of the policy-making cycle (Sadler, 1998). Under this broad perspective, SEA encompasses assessments of both broad policy initiatives and more concrete programmes and plans that have physical and spatial references (Dalal-Clayton and Bass, 2002).

Within the broadest context of methodologies for SA, the need for operational tools to put them into practice may be solved by Decision Support Systems (DSSs), which are assessment tools that provide useable knowledge at an appropriate point of the decision-making process, and at an appropriate level of precision.

A DSS is a computer-based instrument that facilitates the processing, analysis and presentation of information. It helps decision makers to identify which information is relevant at any given time in the policy-making process. With this information, the quality of the policy-making process can be enhanced. On the one hand, a DSS assists with policy analysis by forecasting of future contexts, design and screening of alternatives, impact assessment, and comparing and ranking alternatives. On the other hand, a DSS involves more process-like actions such as communication or interactive and participative decision-making processes.

4.3 A METHODOLOGY FOR SUPPORTING IWRM FOR SUSTAINABLE DEVELOPMENT

The following pages present a methodology developed within the MULINO Project (Giupponi et al., 2004) for integrating the four steps described above, in which knowledge relevant to sustainability science is used for decision making in IWRM. The next paragraphs describe how indicators and indices (i), managed within a conceptual framework (ii), can be utilised in specific forms of analysis (iii) and assessments (iv), for the implementation of IWRM principles in decision making.

4.3.1 The Conceptual Framework and the Role and Management of Indicators

Within the IWRM context the initial task of decision makers is acquiring knowledge about the river basin by collecting information about human activities and their impacts on the environmental systems. This task may be based upon the identification of suitable indicators, which can provide concise quantification and temporal monitoring of the main human and environmental variables.

The whole process should be then formalised within a conceptual network, in this case based upon the DPSIR approach. In a conceptual framework for natural resources management, and in particular to IWRM, the Impacts describe the existing problems arising from the change detected in State variables, which affects their economic value, environmental function and social role. The level of the responses has to be related to the magnitude of the impacts. These different responses need different planning processes, and different decision makers could be involved. The different planning levels could be policies, plans, programmes and projects, from macro to micro level. As previously mentioned, as far as water resources are concerned, the spatial level is usually defined by the physical boundaries of the hydrological subdivisions of the land: river basins and sub-basins. Nevertheless, various levels of response may be identified for local, regional and national decision makers. For instance, local decision makers (e.g. municipal water administrators) do not deal with responses at the Driving forces level with sector policies. Instead, they may act with plans on Pressures, or with specific projects affecting the state of the environment. Conversely, the higher level policy-making bodies usually act on Driving forces and Pressures, having fewer possibilities to deal directly with environmental conditions, or State. In any case a coordination effort may be required in order to produce an efficient response.

A crucial aspect of applying the DPSIR approach to the principles of decision making in IWRM is the transformation of a static reporting scheme in a dynamic framework for integrated assessment. The next two paragraphs present how Integrated Assessment Modelling (IAM) combined with Multi-Criteria Decision Methods (MCDMs) can provide support for analysis and assessment procedures.

4.3.2 Methods of Analysis: Modelling and Evaluation

The implementation of IAM in the DPSIR framework is approached by focusing on the DPS part of the conceptual framework. These three elements were considered as formalisations of driving variables, model parameters and outputs, respectively. In the case of water pollution models, for instance, Ds represent the forcing variables ruling the behaviour of the simulated system (i.e. the catchment). Ps may be represented by parameters that express the rate of pollution processes and Ss are the output variables quantifying the dynamic evolution of the catchment system, as affected by the pollution sources and processes. Integration of models may occur at various levels and in different ways and thus relationships could be expressed by parallel one-to-one flows, or one-to-many (e.g. one activity affecting various environmental compartments), or many-to-one (e.g. various sectors affecting the same environmental indicator), or even many-to-many, in the case of multi-sector integrated models.

In the context of environmental decision making, IAM can thus support the identification of the correct Responses by providing sets of indicator values derived from simulations. Several model(s) runs are needed in which every run is parameterised to represent the expected consequences for one option in turn, within the set of alternative responses to be examined. However, a crucial step is needed: the development of a set of evaluation indices, targeted in particular to evaluate Impacts derived from the State indicators. Evaluation procedures may be implemented by focussing on the link between S and I and between I and R by adapting concepts and methods derived from the literature about Multi-Criteria Decision Methods, and in particular Multi-Attribute Methods (Hwang and Yoon, 1981). Within this disciplinary context a preliminary phase of Problem Structuring is targeted towards the identification of those factors to be considered for choosing between previously defined alternative response options. These factors are expressed as indicators derived from output variables of IAMs or monitoring activities and used to fill the cells of the Analysis Matrix (AM). The step between the quantification of State variables in the AM and the identification of Impact evaluation indices can be conceptualised as the conversion of the AM into an Evaluation Matrix (EM), which expresses the estimated impacts (see Figure 4.6).

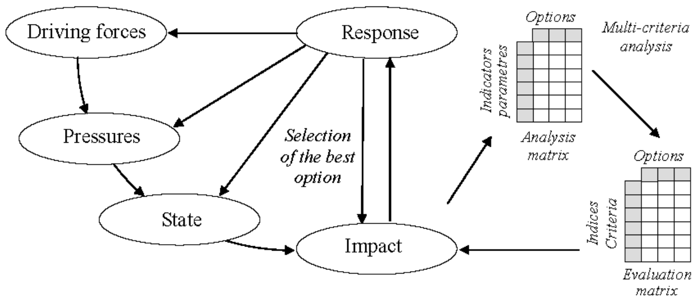


Figure 4.6 Implementation of MCA techniques within the DPSIR framework

This step is realised by means of normalisation procedures and value functions, allowing respectively the comparison of multidimensional indicators/factors and the expression of judgements to convert their scales into evaluation criteria, specific to the decision in question. The standardisation procedure simply transforms any arbitrary data range to a standard interval which represents the degree to which a decision objective is matched by every possible value of the indicators stored in the AM. The value function is in practice a mathematical representation of human judgements. The way the performances of the alternatives are translated into value scores is controlled by the decision maker's preferences. Weights are usually applied to evaluation criteria to contribute to making explicit the preferences of the decision maker.

Having identified the impacts, the decision maker has to apply decision rules to the values stored in the EM to determine the preferred option, and therefore filling the gap between I and R. In the simplest case the rule can be expressed by the weighted sum of values stored in the columns of the EM. Various iterations are possible at this step to refine the selection of the preferred response by considering the results of the sensitivity analysis, refining the weights, or choosing alternative decision rules. Parallel procedures are also possible in multi-stakeholder group decision making.

4.3.3 Assessment Methods: a Dynamic and Integrated DPSIR-DSS Tool

Many decision support systems have been developed to address the problems of water resource management (Mysiak et al., 2002). DSSs can improve the quality of decision making by combining the capabilities of geographical information systems, database technology, modelling techniques and optimisation procedures into one computerised system. Furthermore, openness about how decisions are reached is greatly facilitated using a DSS in which effects of alternative development policies can be explained and their impacts assessed in a form which can be comprehended by the non-expert. Similarly, a DSS is ideally suited to answering questions arising from policy changes on water resources by providing the understanding of the processes involved, evaluating the consequences and delivering advice.

The main objective of the MULINO project was to improve decision making in sustainable water resource management at the catchment scale, in compliance with the recently released Water Framework Directive, WFD (EC, 2000). In accordance with the WFD, the DSS developed by the project integrates hydrological and socioeconomic approaches in order to assist water authorities in the management of water resources.

Converting the DPSIR framework in a dynamic environment through the implementation of IAM procedures, posed no problem until the issue of multidisciplinary integration was touched upon. When social and economic considerations were brought into the IAM environment, the DPSIR approach was limited by its static environmental monitoring and reporting.

Two main alternative solutions were examined in order to expand the DPSIR context to social and economic issues. The first solution consisted of reconsidering the definition of State by broadening its meaning to include socioeconomic indicators. The second consisted of maintaining the restrictive environmental meaning that focuses socioeconomic analyses on the D component. Pros and cons were evident for both solutions. The first allowed a more explicit representation of causal links and processes within the catchment, but lost coherence with the original – or at least the common – terminology, while the second was more coherent but probably less effective in representing the territorial system (the catchment or river basin) and the decisional process.

The second solution was adopted because it was considered sound, from a theoretical viewpoint, to represent causal links between social and economic drivers and the state of the environment through the DPS chains, thus restricting socioeconomic aspects to the origin of the chain. For example, social indicators of driving force, such as ‘Unemployment rate’, can be included in a model assessing environmental impacts in a given territorial context. This is valid for analysis conducted at broad territorial scale in particular. With this in mind, in contrast with some interpretations of the DPSIR framework, it was also considered useful to include within D indicators non-socioeconomic drivers such as climate change. This solution required an expansion of the IAM environment to not only deal with D-P-S chains, but also with ‘within D’ modelling, in the cases where the responses determine dynamic processes modelled within the socioeconomic systems.

This is true, in particular for applications conducted at broader scales, where responses at the D level are considered in the form of new policies or regulations. Feedback effects of environmental changes in this context are possible in two ways: (i) by closing the DPSIR cycle, or (ii) by internal DPS loops. Both are consistent with the framework presented herein.

A key issue is to guarantee the possibility of feeding decisional matrices with social, economic and environmental criteria, to allow decisions to be taken in a perspective of SD. This aspect was tackled by allowing D and P indicators to be considered as decision factors within the AM.

For the sake of concreteness, the application of the methodology described above to a pilot study in the area of the Venice Lagoon Watershed (VLW, north-east Italy) is presented in the next section. The mDSS tool (Giupponi et al., 2004), in which the methodology developed by the MULINO project has been implemented, has been applied to support a recent decision problem of a water management authority (the Destra Piave Reclamation Board) in the Vela catchment.

4.4 A PILOT STUDY APPLICATION IN THE VENICE LAGOON WATERSHED

The Venice Lagoon and its watershed form an environmental system of approximately 2500 km^2, where historical and recent cities, large and medium-small industrial districts and intensive agricultural activities coexist within a peculiar natural area. The drainage basin consists of a low-gradient floodplain with a surface of about 2000 km^2. It is drained by water courses with different hydraulic regimes (natural, mechanical, alternate mechanical). About 40 per cent of the basin surface is below mean sea level and is under reclamation by pumping machines. The pollution discharged into the Venice Lagoon by streams and canals flowing through the catchment represents a substantial contribution to the overall pollution budget of the Lagoon and is a major environmental issue.

In Italy public funds are made available by specific national and regional regulations in order to support the realisation of initiatives for the abatement of pollutant loads that travel from the catchment into the lagoon. To apply for those funds, local agencies in charge of water management can present suitable projects targeted at reducing diffuse pollution in the drainage basin. One of the recipients of such funds are the Land Reclamation Boards, public administrative bodies made up of all the private individuals who live or have economic activities in a given territory requiring water management (defined according to hydrological and administrative criteria). Their main task is that of managing the water distribution system, protecting the territory from floods, and managing and maintaining the public infrastructure for land reclamation and irrigation.

The pilot study for mDSS focuses on the choice among alternative environmental engineering operations, such as revitalising and re-naturalising water courses, in order to reduce non-point source pollution (agricultural and other sources) of surface waters.

The Vela Catchment, 100 km^2 in size, is located in the Venetian floodplain. In the north, along the spring belt, soils sit on a deep geologic layer of gravel, while the southern part of the catchment is characterised by deep alluvial soils with various textures. From the hydrologic point of view, the area is thus characterised by varying natural vertical flows of water to the aquifer and a dense surface network of natural rivers and artificial canals. Some areas drain naturally while others, mainly located in the southern part where low lying lands dominate, drain mechanically by means of pumping plants. Intensive crop production (mainly maize), livestock production and fragmented urban areas not yet adequately served by waste water treatment plants act as main driving forces affecting water quality of the Vela catchment, substantially contributing to the overall pollution budget of the Lagoon.

In the problem-formulation phase (Conceptual Phase), once the exploration of available indicators for Driving forces, Pressure and State is concluded, DPS chains representing the problem's underlying cause-effect relationships are constructed (Table 4.1). Some chains are incomplete, in particular those related to the socioeconomic drivers that are relevant for the decision but do not provide significant environmental consequences.

At the end of this phase the problem is described in a cognitive and structured way (DPSI) and the area of interest and relevant database inspected. The Impact, that is the problem for which a Response is needed, in this case stands in general as the degradation of the Lagoon's ecosystem.

In the Design Phase, for the sake of simplicity, only three options were selected to present the MULINO approach and mDSS, out of an original list of twelve alternative projects:

1. Excavation of a tributary, the Meolo River, in order to increase water retention time (EXCAV_MEO). Rivers have the natural capability of diminishing pollutant contents through dilution, deposition and absorption processes, as well as through purification with microbes;
2. Plantation of a buffer strip of trees along the riverbank of one of the main rivers of the catchment, the Vallio River, to improve the phytoremediation effect (BUFF_VALLIO). Vegetation filter strips have been identified as a best management practice that has the potential to remove substantial amounts of sediments and nutrients from cropland and urban runoff;

Table 4.1 DPS chains for the Vela catchment

Driving force indicators (D)	Pressure indicators (P)	State indicators (S)
Urban settlements (inhabitants/km^2)	Urban net emission of BOD5 (t/yr)	BOD/COD in rivers (mg/l)
Impermeable (developed) areas (ha)	Loads of hazardous substance to water bodies by sector (tHS/yr)	Hazardous substances (pesticides) in rivers (µg/l HS)
Irrigated land (ha)	Use of water for irrigation (m^3/yr)	N uptake with crop irrigation (t/yr)
Buffer strips (ha)	Drainage water interception by vegetation (m^3/yr)	N uptake with buffer strips (t/yr)
		Nitrate concentrations in water bodies (mg/l)
Use of nitrogen fertilisers in agriculture (kg/ha/yr)	Nitrogen balance: total surplus from fertilisers and manure applications (kg/ha/yr)	Flooding damages (MEur)
Land reclamation by pumping machines (m^3/yr)		Self-remediation of water bodieN retention (t/yr)
Land reclamation by drainage network (m^3/yr)	Hydraulic risk: return time (yr)	
	Total discharge of nitrogen (t/yr)	Water retention time (hrs)
Land reclamation by drainage network (m^3/yr)		
Social conflicts (index)	Surface water drainage (mm/yr)	
Bureaucratic pressure (index)		
Variation of social welfare (index)		
Local legislation (index)		
Public investments (MEur)		
Maintenance costs (Eur/yr)		

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3. Redirection of the discharge of an area (153 ha) from the Vallio River into the Candellara Canal, that flows outside the lagoon (DIV_CANDE). This option prevents a certain amount of nutrients flowing into the Lagoon.

The first two operations are mainly intended to increase the capacity of water courses in terms of self-purification, in-stream storage and retention times to obtain a reduction in diffuse pollution. The third simply diverts a certain amount of pollutants away from the Lagoon (Figure 4.7).

Environmental engineering projects such as revitalising and re-naturalising water courses have a good capacity of reducing pollution loads. But they can also have other functions such as upgrading the farming landscape and improving the recreational use of rural areas. The decision-making process is therefore complicated by this multi-functionality that operates in the territory and that combines hydraulic engineering, natural resources management, recreational activities, etc.

A set of appropriate decisional criteria, ranging from environmental impact indicators to expressions of political will, were subsequently chosen from the list of indicators used to build the DPS chains. The selection of the criteria was aimed at determining a scale of preferences that consider the objectives and functions of the Board and that reflect those stated in the regional regulations. For instance, criteria that reflected a possible change in the irrigation availability were considered important.

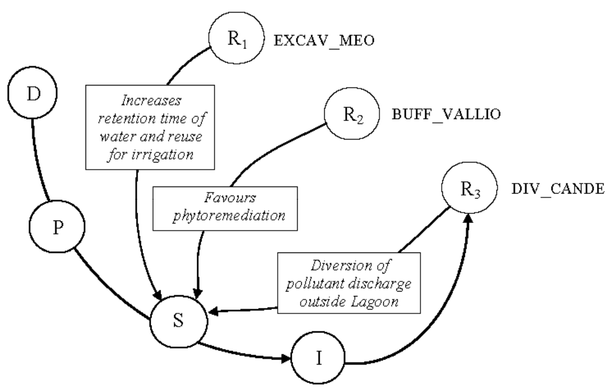

Figure 4.7 Set of alternative responses that may improve the water quality of the Vela catchment

The estimation of resulting changes of indicator values lead to the effectiveness assessment of the three alternative options: first the performances of each criteria were calculated and stored in the Analysis Matrix (Table 4.2). Then each criterion score was translated into a value score that made explicit, through appropriate value functions, the DM's preferences, and therefore the degree to which the main goal was matched by each alternative option. These operations led to taking the decision process a step further: the Choice Phase.

As previously stated, decision problems involve criteria of varying importance. Criterion weights, that provide information on the relative importance of the considered criteria, were assigned. A vector of weights was obtained using the procedure of pair-wise comparison implemented in the software, using the judgements expressed by the Board's technical staff. The reduction of hydraulic risk, the irrigation value and the financial constraints resulted in being the most important parameters for the ranking of the alternative projects.

Once the weights are defined, the evaluation criteria are aggregated by means of a specific decision rule. This is the procedure by which criteria are

Table 4.2 Analysis matrix built with criterion indicators extracted from the DPS chains reported in Table 4.1

Criteria	BUFF_VALLI	DIV_CANDE	EXCAV_MEO
D: Impermeable (developed) areas (ha)	2.716	0.000	0.000
D: Use of nitrogen fertilisers in agriculture	0.876	0.004	1.171
S: Water retention time (hrs)	3.500	0.000	3.000
S: Self-remediation of water bodies: N ret	0.338	9.839	0.170
S: N uptake with crop irrigation (t/yr)	1.664	0.000	33.281
S: N uptake with buffer strips (t/yr)	15.000	0.000	0.000
D: Urban settlements (inhabitants/km^2)	2.005	0.000	0.000
D: Social conflicts (index)	0.000	1.000	0.000
D: Bureaucratic pressure (index)	0.132	0.075	0.034
D: Variation of social welfare (index)	0.067	0.127	0.057
D: Maintainance costs (Eur/yr)	0.042	0.079	0.074
D: Local legislation (index)	0.032	0.167	0.085
P: Use of water for irrigation (m^3/yr)	100.000	0.000	2 000.000
P: Hydraulic risk: return time (yr)	0.022	0.149	0.072
D: Public investments (MEur)	300.000	250.000	200.000

selected and combined to arrive at a single final score for each option, and by which evaluations are compared. The Simple Additive Weighting (SAW) method was the first chosen for testing mDSS. Using the preferences expressed by the Board, DIV-CANDE (diversion of the discharge of part of the catchment through the Candellara canal with outlet outside the Lagoon) resulted in being the most suitable option. A sensitivity analysis carried out on the results of the SAW decision rule enabled the exploration of the options' performances. It was observed that a small increase in the weight of 'Nitrogen uptake with buffer strips' (from 0.04 to 0.14), lead to a change in the option's rank order by reversing the best with the second best option (BUFF_VALLIO). Therefore, the choice of the option recommended by the SAW method using the Board's criterion weights was neither very robust nor stable, and this can be observed by the very similar value of the overall performances.

The Order Weighting Average (OWA) required a second set of (order) weights that allow one to control the trade-off level between criteria and that describing the risk behaviour of the decision maker. The order weights are not assigned to the criteria, but to the position of the rank order defined by the criterion values of an option. According to this, the first order weight is assigned to the criterion with lowest outcome value and the last order weight to the criterion with highest outcome value for an option. To test the method, five sets of order weights were applied to the 15 criteria:

1. The order weights [0, 0, 1] assign extreme importance to the five highest criterion scores (0.2 each). This yields an aggregation operator with a moderate degree of trade-off between criteria and a high degree of Orness (absence of compensation between criteria with good and bad performances), representing the most risk-taking behaviour;
2. The order weights [0,1,0] assign extreme importance to the five middle-ranked criterion scores. This yields an aggregation operator with a moderate degree of trade-off, as well as of ANDness (compensation) and ORness;
3. The order weights [1, 0, 0] assign extreme importance to the five lowest criterion scores. This yields an aggregation operator with a moderate degree of trade-off between criteria and a high degree of ANDness, representing the most risk-adverse solution;
4. The order weights [0.5, 0, 0.5] assign same importance to the highest and lowest criterion scores (0.1 each). This yields an aggregation operator with substantial trade-off and a moderate degree of ANDness and ORness;
5. The order weights [0.33, 0.33, 0.33] apply equal importance to all criterion scores (a weight of 0.066 each) and thus do not change the existing ranking order: the result is equivalent to that of the SAW rule, for which full trade-off is allowed.

As a result (Table 4.3), the option DIV_CANDE is the preferable one in most of the cases and EXCAV_MEO the least desirable. BUFF_VALLIO stands up as the best option in the case of a risk-averse behaviour. This is due to the fact that greater significance is given to criteria related to the self-purification capacity value of the options.

The Ideal point methods order a set of alternatives on the basis of their separation from the ideal and negative-ideal solutions. The ideal solution represents a hypothetical alternative that consists of the most desirable level of each criterion across the options under consideration. The negative-ideal solution consists of the least desirable level of the options' performance. The best alternative is the one closest to the ideal point and most distant from the negative-ideal solution. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is one of the most popular compromise methods. This method's outcome is different from those of the previously-presented decision rules, as it indicates BUFF_VALLIO as the best option, confirming the very close performance of two of the three options (as demonstrated also by the sensitivity analysis). Furthermore the TOPSIS method goes beyond the simple closeness to the ideal solution by considering the closeness to the less desirable solution as well.

In view of testing every capability of the software, a simulation of group decision making was also performed. A parallel assignation of weights was carried out with a group of students simulating an environmentalist group: higher weights were assigned to criteria relevant for the environment and the landscape (e.g. nitrogen uptake through buffer strips). In general criteria linked to the processes involving a natural reduction of nitrates were assigned higher weights.

As a result, the SAW method gave the plantation of buffer strips along the Vallio river (BUFF_VALLIO) the best ranking score. The level of problem understanding and preferences of the two groups considered were different, but assuming they were willing to come up with a compromise solution, the very simple group decision-making capability of mDSS helped in finding a common final solution. The Borda technique is a very simple algorithm implemented in

Table 4.3 Final scores resulting from application of different sets of order weights in the OWA rule

Order weights	DIV_CANDE	BUFF_VALLI	EXCAV_MEO
[0, 0, 1]	0.086	0.074	0.07088
[0, 1, 0]	0.0204	0.0099	0.00876
[1, 0, 0]	0.00016	0.0	0.0
[0.5, 0, 0.5]	0.043	0.03708	0.03544

mDSS, which assigns ranks to decision alternatives based on the rationale that the higher the position of an alternative plan on the voter's list, the higher the rank assigned. DIV_CANDE is the compromise solution in this case.

CONCLUSIONS

The literature review indicated that there is a clear need for methodologies and tools to put sustainable development principles into practice, in which decisions and choices are assessed in terms of their sustainability, not only over the long term, but also with regards to their day-to-day contribution to sustainable development.

This may also be described in terms of the implementation of an integrated framework allowing decision makers to choose first and then to monitor the process induced by their decisions. IWRM falls within this domain, thus requiring ad hoc approaches tailored to the specific needs and peculiarities of water resources.

The development of environmental policies has led to the need to utilise the wealth of data and scientific knowledge that has become available and can support integrated water resources management. Various methods and tools, such as modelling, environmental impact assessment and decision support, can provide rational insight into the system's behaviour and the problems addressed. However, integration remains a difficult issue.

The four-step process described above may help cope with the problem mentioned above, focussing in particular on:

1. The complexity of the decision making process that is typical of IWRM;
2. The large amounts of multi-sectoral and multidisciplinary information;
3. The need for efficient communication between the scientific and policy sectors and between decision makers and the stakeholders.

The DPSIR scheme proved to be sufficiently broad to allow the formalisation of the whole procedure of decision making in the context of sustainable water management, but a great number of analyses are necessary to develop an integrated and dynamic DSS tool upon that basis. The resulting methodology, and the application tool presented above, combined the innovative potentials of IAM and MCA approaches, with the effective communication potential of the well-known DPSIR approach.

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4.3 MULTI-CRITERIA DECISION MAKING IN WATER RESOURCES MANAGEMENT

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5. Multi-Criteria Decision Making in Water Resources Management

J. Feás and P. Rosato

5.1 INTRODUCTION

Water management is one of the main issues for human development. Water can be considered the most important primary good, and is very closely related to social and economic development. Water is generally a limited resource that must be managed efficiently for its conservation and future uses, but must also be distributed with equity.[1]

Water is a natural resource that has always played a strategic role in both social and economic development although this role differs with reference to both space and time. It is extremely difficult to generalise the problems concerning water management, which are specific and depend on the physical, economic and social characteristics of the considered context. In other words, it is not easy to find a common model to manage water resources in Africa and the Far East or in the Venetian Plain. Furthermore, water is an economic enigma: a human right, a production factor, and a luxury good. Therefore, many issues must be taken into account in water management. Firstly, the multipurpose use of water. Water resources are used for multifunctional purposes and managed by different water institutions with different final objectives. In fact, together with the consolidated civil and production function of water, it plays a protection function for the environment and a recreational function for which demand is rapidly increasing.

The different water uses and the many relationships with surface and groundwater systems are represented in Figure 5.1. In general, five different uses of water can be considered: for generating energy, irrigation in agriculture, drinking water for humans, production for industry, and for recreational services. The inflows represent water demands for each use that are usually in conflict because of scarcity and the impacts of some uses on water quality. The outflows represent the wastewater returned to the system, more or less polluted. All flows (in and out) are highly dependent on one another. The multi-functionality of the scarce water resources makes it extremely difficult to satisfy all the demands, and generates a great deal of

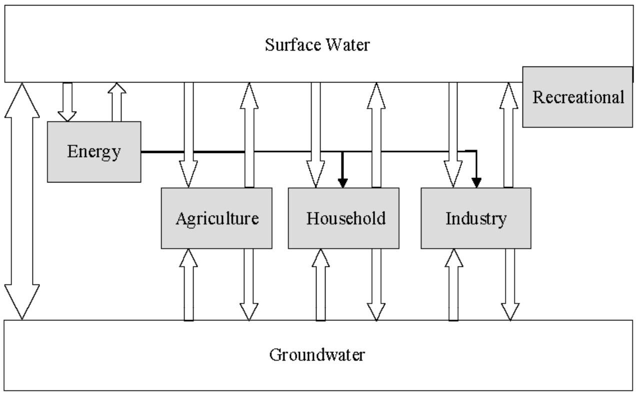

Figure 5.1 Water uses

conflict in use priorities. These conflicts are exacerbated by population growth (particularly in areas where water scarcity is rife) and by the growing importance of industrial versus agricultural production and by the growing social sensibility for the protection of the environment.

For these reasons, a global and sustainable perspective for integrated water resources management is strongly required and a lot of effort has been made in recent years to establish the basics for adequate integrated water resources management (EU Water Framework Directive, 2000).

The necessity to pursue an integrated water resources management by the public authorities produces a strong demand for operational tools in order to support decisions in this difficult task. In recent years, many advances have been made in technical tools for modelling water resource problems, and multi-criteria decision making (MCDM) procedures are widely considered very useful in challenging conflicts related to water management. This usefulness relies on the logical structure of the valuation procedures and on the common language developed for defining and discussing complex water problems. It is also a useful tool for communication purposes, between those who have to make the decisions and those who are affected by the decisions. Finally MCDM easily includes in the decision making process the effect of uncertainties that often characterises water management problems.

This paper illustrates the MCDM approach in integrated water resources management (IWRM). Firstly a brief description of the basic terms and concepts in MCDM is presented and the most popular multiple criteria decision analysis methods are illustrated. A survey is presented of the different methodologies applied to water resources management within different contexts, number of decision-makers and water problems. To complete the chapter, some conclusions are made on the use of this kind of techniques in the past with some thoughts on future developments.

5.2 MULTI-CRITERIA DECISION MAKING

In the previous section, the need for an integrated management that is able to combine private and public/social use of water resources was presented. At the present time, considerable ongoing research to develop support instruments for this IWRM is being undertaken, with a significant role being played by the MCDM technique.

The study of the decision process, in particular the methods to adequately understand and represent the structure of preferences of a decision-maker in order to find a satisfactory decision, has led, in the last twenty years, to the elaboration of an operational research methodology based on multiple objectives and criteria. There are many applications of these methodologies in natural and other resources management.

There is no generally accepted taxonomy of the different multiple criteria decision analysis methods. In the present chapter, we define MCDM as a general term to identify various formal approaches, which take into account explicitly multiple criteria in helping decision makers (Belton and Stewart, 2002). Other terms are widely used by different authors to identify similar concepts: multiple criteria analysis, multiple criteria decision aid, and so on.

In the study of the decision process in complex environments, the terms 'multiple objectives', 'multi-attributes', 'multi criteria', 'multi dimensional', and so on, are used frequently. In many cases, they are considered synonyms because a universal definition has not yet been found. The term MCDM has been therefore used to cover all the general methodologies.

In order to understand the structure of MCDM models and not just the context in which they are or may be used, it is worth evaluating the terminology adopted. This is because recent methodological developments have highlighted a further need to define more precisely the terms currently in use. In fact, most of the key words that will be identified have similar meanings and are often used indifferently. Therefore, apart from creating confusion, this can also lead to a wrong analysis of the methodologies.

Zeleny (1982) proposed a reference for use of the terminology, together with Romero and Rehman (1989) and Goicoechea et al. (1982). This collection of definitions is useful and interesting because it also helps in the classification of the various current developments in MCDM. Terms like decision variable, attribute, objective, target or goal that need a clarification are presented bellow.

- Decision variable: decision variable represents the lever on which the decision maker operates. Thereby it represents all the aspects within which the user decides to act. In IWRM, the main decisional variables are water quantity allocated in different uses, water quality standards required, and so on.
- Attribute: The attribute is a parameter that represents any particular aspect of a given problem assumed by the decision-maker to make their decision (income, savings, employment, debt, pollution level, and so on) It is objectively determined and normally expressed as a mathematical function of the decisional variables.
- Objective: The objective is the direction (min or max) that the decision maker chooses to follow for a certain attribute (that is to maximise a specific output as profit or minimise pollution, and so on).
- Target: The target is the value set by the decision maker as a reference point for the attribute chosen.
- Goal: The goal is the expected level of the chosen attribute that the decision maker aims to achieve with their decision (that is amount of water for irrigation, nitrate levels in water, and so on).

The definitions provided above may cause some confusion. In fact the distinction between some of them, seemingly obvious, is sometimes ambiguous; in particular that between goal and target and even more so between objective and goal. On the other hand, the definition of these terms in the specialist literature is not univocal; in Goicoechea et al. (1982), goal and target are synonyms whilst the term objective frequently has a more general connotation and goal reassumes the definition of objective and target. It should therefore be stressed that the aforementioned definitions permit a more rigorous classification of MCDM methods according to the characteristics of the decisional process.

Various problems are encountered in MCDM, which for our analysis can be divided into two main categories:

1. Multi objective decision making (MODM);
2. Multi attribute decision making (MADM).

In both categories, the user can take into consideration more, conflicting, evaluation criteria for which units of measurement differ. In the MODM methods, the decision process concerns the identification of the best choice within an infinite set of alternatives, defined by the constraints of the problem. In MADM methods, instead, the method guides the decision makers among a finite set of decisional alternatives.

On a general level, as observed in Rehman and Romero (1993), the existence of multiple objectives in the decision process brings about a fundamental qualification of the utility function that, contrary to the neo-classical economic analysis, is based on more factors. This is shown in the following optimisation model:

$$Max\, U = u[C_k] \quad \text{with} \quad C_k = f_k(\boldsymbol{x}) \quad \text{and} \quad \boldsymbol{x} \in X \qquad (5.1)$$

where

U is the total utility of the decision-maker to maximise;
u is the function that expresses the utility with respect to the k decisional criteria;
C_k represents the criteria (attribute/objective);
$\boldsymbol{x}$ is the vector of the decisional variables.

The set X identifies the region of feasible solutions that is continuous in MODM problems (infinity alternatives); in this case, the objective of the decision maker is to identify the best solution to the problem. However, in MADM problems this region is represented by a discrete set of vectors of decision variables, each representing a predefined alternative solution and the objective of decision maker is to create a ranking.

In Table 5.1 (Hwang and Yoon, 1981, modified), the main characteristics of the two approaches are shown.

In the next paragraphs, some of the most popular methods for both approaches are illustrated. The objective is not to present an exhaustive description of the models, just some basic concepts to understand the different perspectives to assist decision making problems.

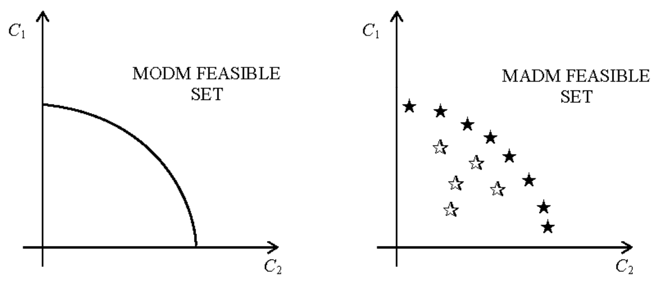

Figure 5.2 Feasible sets in MODM and MADM

Table 5.1 MADM versus MODM

	MADM	MODM
Criteria	attributes	objectives
Objectives	implicit	explicit
Attributes	explicit	implicit
Constraints	inactive	active
Alternative	finite, discrete	infinite, continuous
Use	selection, evaluation	design

5.2.1 The Multi Objective Approach

The multi objective approach is a development of traditional mathematical programming models of which much of the structure is retained. Research into methods for scientifically tackling decisional processes has often used mathematical programming because, by organising the information coherently with the theory, it can be used to formalise the operational reality in a mathematical model able to represent the pursuing of the chosen objectives. Obviously, the representation of reality has to be 'stylised' but, with its rational structure, it can provide the analyst with a good simulation of the economic facts and an acceptable approximation of the decisional processes (Hazell and Norton, 1986). MODM methods support decisional problems in which the decision space is continuous and the objectives are established for each of the criteria. No predefined set of solutions exists in these models, so the process seeks to discover the best option.

Traditional mathematical models are based on the assumption that the decision-maker formulates choices with respect to a well-defined parameter. In fact, these models generally take the form of the classical linear programming model, that is:

$$\max/\min Z = \sum_{i=1}^{n} c_{ji} x_i \quad \text{with} \quad \sum_{i=1}^{n} a_{ji} x_i \le b_j \qquad x_i \ge 0 \qquad (5.2)$$

where:

c_i = contribution of the i^{th} decision variable to the optimisation of the objective function;
x_i = decision variable;
a_{ij} = use level of the j^{th} resource to accomplish one unit of i^{th} decision variable;
b_j = availability of the j^{th} resource.

The problem is therefore solved by finding the vector $\boldsymbol{x}$ that optimises (max or min) Z according to the availability of resource b_j. This approach assumes that the decisional rule is to optimise just one parameter (Z).

This assumption greatly reduces the interpretative potentials of the linear programming model, as the decision-maker does not usually make a choice based on just one parameter, but refers to a multi-criteria utility function. It is worth stressing that if a choice must be made on the basis of just one objective it is not an economic choice but more a technical question of measurement and research (Zeleny, 1982). The decisional problem arises when there is more than one conflicting objective to be pursued contemporarily and reasonable compromises must be identified.

Therefore, based on this assumption, the solving of a linear programming model cannot be taken as an optimisation of the allocation of a given supply of resources but rather as a method of searching for the combination that guarantees the best performance with respect to a given objective. The problem therefore is to make a decision with regard to more than one conflicting decisional parameter.

Consistently with the definition of terms given in the previous section, we can have a decision-maker who:

1. operates with more than one conflicting objective (without an expected level for the relative attributes);
2. decides on the basis of a given number of conflicting goals.

In the former case the technique to use is multi-objective programming (MOP) and related developments (compromise programming), aimed essentially at identifying efficient solutions with respect to the objectives expressed by the decision-maker. In the latter case, goal programming (GP) is adopted on the basis of which the decisional problem is resolved by finding the solution closest to the set of goals stated by the decision-maker.

Multi objective programming

The MOP techniques are used when the decision-maker tries to achieve a set of objectives at the same time, but satisfactory levels are not established. The MOP seeks to solve the simultaneous optimisation of several goals under a set of constraints, linear and non-linear. The method identifies a set of efficient solutions.[2] With such a formulation, it is obvious that it is not possible to identify just one optimal solution to achieve all the objectives at the same time.

On the basis of this assumption, the structure of the MOP model remains as follows:

$$EFF\,[\,f(x)\,] = [f_1(x), f_2(x), \ldots, f_n(x)] \quad \text{with} \quad x \in X \tag{5.3}$$

where *EFF* is the 'search for efficient solutions' and *n* are the objectives to be pursued.

Efficient solutions can be identified in different ways. The most widely used are the weights method, constraints method and methods for estimating the non-dominated set (non-inferior set estimation method, NISE). Their diffusion is essentially due to the fact that they can be applied using the standard simplex algorithm.

In the weights method, the functions expressing the different objectives are combined in a single objective function through the application of weights. These weights are initially attributed arbitrarily. The model has the following structure:

$$\max/\min \sum_{i=1}^{n} w_i\, f_i(x) \quad \text{with} \quad x \in X,\ w_i \geq 0 \tag{5.4}$$

The set of efficient solutions are generated by parameterising the weights w_i. For each set of weights, an efficient solution is generated; obviously, the precision with which the set is produced depends on the size of the steps with which the weights are varied reciprocally. The smaller the step, the higher the number of efficient solutions there are and the better the approximation.

The constraints method uses a model in which one of the objectives is set in the objective function, while the others are transformed into constraints:

$$\max/\min\ f_j(x) \quad \text{with} \quad f_i(x) \leq L_i,\ x \in X,\ i \neq j \tag{5.5}$$

The set of efficient solutions is generated by parameterising the constraints L_i. This method guarantees the efficiency of the solutions produced only if the parameterised constraints are limiting in the optimisation process. Also in this case, the precision with which the efficient set is generated depends on the size of the steps with which the constraints are parameterised.

In the search for the set of efficient solutions with both weights and constraints methods, a sensitivity analysis, which can identify the variations to give to a weight or constraint to vary the solution, can be enormously useful.

From what has been described above, it can be deduced that there are essentially two, partly interrelated, weak sides to the MOP. The first is the huge amount of computation due to the large number of iterations necessary to identify the set of efficient solutions. The second is the decision-maker's possible uncertainty when faced with the high number of efficient solutions. There is a need to identify methods for reducing the number of efficient solutions to simplify both the calculation phase and/or the decisional one. Compromise programming (CP) is probably the most widely used method and will be presented in the following paragraph.

Compromise programming

Compromise programming (CP) was proposed by Zeleny (1973) as a method for pruning the set of efficient solutions consistently, with the preferences of a rational decision-maker who attempts to make a decision.

The basic assumption is that the decision-maker aspires to come as close as possible to the solution that they consider ideal (see also next section). In order to model this tendency an objective function must be defined and this is the measure of the distance between the set of efficient solutions and the ideal one. Obviously at this point it is not important to define a geometric function (Euclidean) of the distance but rather a relation that simulates the attitude of the decision maker as precisely as possible.

A generalisation of the concept of distance in n dimensions (criteria) between an ideal solution and an efficient feasible solution is represented by the following equation:

$$\overline{DI}_p = \left[\sum_n | i_n - d_n |^{\mathrm{P}} \right]^{1/p} \tag{5.6}$$

where:

i_n is the ideal solution;
d_n is the efficient feasible solution from which a different measure for each value of p can easily be obtained and which, for p equals 2, the Euclidean distance is obtained.

Two of the infinite values of DI_p appear to be especially interesting for simulating the decision-maker's preferences, that is those corresponding to $p = 1$ and $p = \infty$. For $p = 1$, the distance is given by the algebraic sum of the absolute value of the gaps with respect to n dimensions. For $p = \infty$ it can be demonstrated that the distance is equal to the maximum deviation among the n dimensions.

From the above equation, it is simple to deduce that DI_1 is the maximum value of the distances that can be considered, while DI_∞ is the minimum.

Using metrics 1 and ∞ it is possible to simulate the two extreme attitudes of a rational decision-maker: on the one hand, the one who takes into consideration all deviations with respect to the ideal solution in a weighted additive way; on the other hand, the one who is careful to limit what becomes the maximum deviation each time. It should be noted that, to compare deviations expressed with different dimensions, preventive normalisation becomes necessary. This can be done in different ways, usually with respect to the maximum interval of variation given by the difference between the best and the worst performance for each criterion.

The CP model can then be written as:

$$\min \overline{DI}_1 = w_n \frac{i_n - f_n(x)}{i_n - a_n}, \quad x \in F$$
$$\overline{DI}_\infty, \quad w_1 \frac{i_1 - f_1(x)}{i_1 - a_1} \le \overline{DI}_\infty, \ldots, w_n \frac{i_n - f_n(x)}{i_n - a_n} \le \overline{DI}_\infty, \quad x \in F \tag{5.7}$$

Solving the model according to the two above metrics, the set of efficient solutions can be reduced, thus simplifying the choice for the decision-maker. It is also possible to reduce significantly the number of computer elaborations, as it is not necessary to identify the whole set of efficient solutions, but just the extreme points (pay-off matrix).

The solutions obtained on solving formula 5.7 identify the so-called compromise set, within which, given the assumptions carried out, the decision-maker should choose. However, the compromise set of solutions is often quite large and so the problems of choice arise again. Regarding this, Zeleny (1974) suggested a procedure (displaced ideal method) through which it is possible to reduce the compromise set coherently with the decision-maker's preferences. This is based on the fact that, although it is reasonable to assume that the decision-maker has the ideal solution as a point of reference, it cannot be assumed that the interval of variation, considered admissible for each decisional criteria, has the dimensions of the difference between the best and worst solution. In other words, it is possible that the decision-maker does not consider acceptable solutions implying a reaching of a significantly higher level in the minor objectives to that identified by the worst solution. These minimum levels in attaining goals are introduced in the model for the calculation of a new pay-off matrix and, consequently, for the redefinition of the space within which to search for compromise solutions. A new compromise set, smaller than the original one, will be obtained through this redefinition. The process can continue with successive reductions of the admissible interval until the compromise set allows the decision-maker to make his choice. Obviously, this is an iterative process that alternately involves both analyst and decision-maker.

Goal programming

Goal Programming (GP) was probably the first method introduced in the field of multi objective decision-making (Charnes et al., 1955). The GP simulates a decisional process that tries to satisfy several predetermined objectives at the same time. In GP, the decision-maker introduces their preferences by establishing satisfactory values for each criterion. The search for the optimal solution is through minimising the difference between the achievement of objectives within constraints and the expected values. These differences are represented and quantified by deviational variables, which can be positive or negative.

The first step in the formulation of a GP model is the identification of the set of criteria to adopt as decisional parameters. An objective value or goal (b_i), considered satisfactory by the decision-maker, must then be defined for each attribute. It is also necessary to specify if that goal must be reached precisely, if it can be exceeded or if some level of non-reaching is admissible.

At this point, the deviational variables for each defined goal are introduced, these can be positive (p_i) or negative (n_i). They represent the deviation in the reaching of a given goal. If the deviation is positive, and the goal therefore exceeded, the positive deviational variable pi represents the excess. If it is negative, the variable n_i represents the deficit. Obviously, given that positive and negative deviations cannot coexist for the same objective, at least one of the deviational variables must be nil. If the goal is fully reached, both variables are nil (Romero, 1991).

Based on this, the pursuing of the generic ith goal can be expressed by the following equation:

$$f_i(x) + n_i - p_i = b_i \tag{5.8}$$

where $f_i(x)$ is the function expressing the value of the i^{th} attribute as a function of the decisional variables x. Now, if the decision-maker wants the value b_i of the i^{th} attribute to be reached from below (for example a given income level), it is necessary to minimise the negative deviation n_i. On the contrary, if the wish is that the goal is reached from higher values (for example a given pollution level), then it is necessary to minimise the positive deviation p_i. Lastly, if the decision-maker hopes that a particular defined goal will be balanced, then the term to be minimised will be the sum of $n_i + p_i$.

In substance, the main characteristic of GP is the search for the optimum solution through minimising the differential between the level achieved with the solutions f_i (x) and the expected levels b_i.

The solving procedure can be done in different ways, in relation to the structure of the decision-maker's preferences. Decision-makers can pursue their goals simultaneously, although with different intensity, or they can attribute an absolute priority to some of them. In the former case, the variant of GP defined weighted goal programming (WGP) is adopted, while the lexicographic goal programming (LGP) version is used in the latter.

The WGP assumes all the goals simultaneously and summarises them in a single objective function. Through this 'compound' objective function, we attempt to minimise the weighted sum of the normalised deviations.

Obviously, normalisation is necessary for comparing criteria expressed in different unit measures, while the weights are applied coherently with the relative importance given by the decision-maker to the various goals. If the objective function and the equation of the constraints are linear, the model can be solved with the simplex method.

The LGP variant of GP uses the concept of absolute priority. In this case, the goals are ranked according to a scale of priorities, and it is assumed that attaining those with a given priority level will take precedence over achieving those with lower levels. Therefore, in an LGP model, attaining goals belonging to high-level priorities will be pursued first, and only subsequently, those of a lower level will be taken into consideration. In summary, the model is solved first by taking the top priority as objective function. The attainment level of related goals is then introduced as a constraint for the next step, where the objective function is the priority immediately below, and so on until all priorities have been used. The final solution is the definitive one.

The WGP and LGP are traditionally considered the two main variants of GP. But many other approaches to MODM, developed subsequently and commonly held to be alternatives to GP, have been revealed on further examination as being specific forms of GP, at least from the algebraic point of view (that is CP).

5.2.2 The Multi Attribute Approach

The MADM methods face decisional problems with a finite number of solutions. MADM guides the choice between n predetermined discrete alternatives (A_1, A_2, ..., A_n) through their valuation with regard to a discrete number k of attributes (a_1, a_2, ..., a_K), for which each alternative has a given performance index, called attributes (a_{ij}). This score can also be interpreted as the result of a function of the relative vector of decision variables referring to each n alternative (i = 1, 2, ..., n), or otherwise:

$$a_{ij} = f_j(x_i) \quad \text{for} \quad j = 1, \ldots, k \tag{5.9}$$

These scores can generally be represented by both quantitative and qualitative attributes. Alternatives and criteria can therefore be related through an evaluation matrix (Goicoechea et al., 1982), the structure of which is shown in Figure 5.3 (see page 113). In some cases, the evaluation matrix already offers a clear ranking of the alternatives. For example, having to select just one alternative, the score of an alternative is the best for all attributes that can occur. It is then a case of absolute Paretian dominance that solves the problem of choice in a simple and unequivocal way (Voogd, 1983).

The identification of Paretian dominated alternatives can be useful for

Table 5.2 Alternatives and decision variables

	A_1	A_2	...	A_n
x_1	x_{11}	x_{12}	...	x_{1n}
x_2	x_{21}	x_{22}	...	x_{2n}
...	...	...	...	...
x_m	x_{m1}	x_{m2}	...	x_{mn}
$\mathbf{x}$	$\mathbf{x_1}$	$\mathbf{x_2}$	**...**	$\mathbf{x_n}$

Table 5.3 Alternatives and decision criteria

	A_1	A_2	...	A_n
a_1	a_{11}	a_{12}	...	a_{1n}
a_2	a_{21}	a_{22}	...	a_{2n}
...	...	...	...	...
a_k	a_{k1}	a_{k2}	...	a_{kn}
$\mathbf{a}$	$\mathbf{a_1}$	$\mathbf{a_2}$	**...**	$\mathbf{a_n}$

reducing the number of columns in the evaluation matrix in the case (more frequent) where the scores do not identify a clear ranking of the examined options.

Many methods can support the choice among defined and Paretian efficient alternatives, to maximise the decision-maker's utility. Although these methods share the same basic information (the evaluation matrix), they differ substantially in terms of quantity and quality of the information required.

The most popular procedures are:

1. Value functions (Keeney and Raiffa, 1976);
2. Analytic Hierarchy Process – AHP (Saaty, 1980);
3. Outranking methods (Nijkamp and van Delft, 1977; Roy, 1985).

These procedures differ by the method with which the preferences are derived and represented in decision-making process.

The value functions methods

The value functions approach is a very popular type of procedure supported by a wide theoretical base that guarantees internal coherence. Moreover, being the very first MADM technique used, there is a great deal in literature that demonstrates its validity in real cases (Beinat, 1997).

This method attempts to obtain a true value for each alternative, which represents the preferences and value judgements of the decision-maker. To obtain this value, a value function is first identified for each considered criterion and the relative importance of each criterion in the global value. The choice is made by identifying the criterion which maximises the multi-attribute value function $f(\boldsymbol{a})$ where $\boldsymbol{a}$ represents the vector of the attributes. The final choice is made by identifying the alternative that maximises the multi-attribute value function.[3]

In the widely used, simplified method with uni-dimensional functions, the a_{ik} scores are normalized from the natural scale into a conventional scale, from 0 to 1, representing the value associated with each impact. On this scale, the first value indicates a situation of minimum utility and 1 indicates the maximum satisfaction for the decision-maker.

$$v_{ij} = f_j\,(a_{jk}) \quad \text{for} \quad i = 1, 2, ..., n \quad \text{and} \quad j = 1, 2, ..., k \qquad (5.10)$$

which when applied to the values in Table 5.3, leads to the construction of a new matrix. This matrix can allow the alternatives to be ranked using, for example, the 'worst case' criterion. This consists of applying a 'max min' logic to minimise the risk of opting for alternatives with low utility levels, even for a single attribute. The minimum value for each alternative is then selected and used to rank the alternatives (Colorni and Laniado, 1989). Many MADM techniques require further information from the decision-maker, that is an expression of the importance or priority of the different attributes. This means defining a vector in which a weight w_j, usually scalar, is associated to each of the j attributes so that:

$$\sum_{j=1}^{k} w_j = 1 \qquad (5.11)$$

Now a new matrix can be obtained of the 'weighted values' z_{ij}, multiplying each value in 5.10 by the relative weight, v_{iz}.

$$z_{ij} = v_{ij} \cdot w_j \quad \text{for} \quad i = 1, 2, \ldots, n \quad \text{and} \quad j = 1,2, \ldots,k. \qquad (5.12)$$

Returning briefly to the 'max min' ranking, the ranking procedure seen before can be applied using data from 5.12, which here is identified as a 'weighted worst case' (Colorni and Laniado, 1989).

Finally, on the 'weighted value' matrix an aggregation procedure must be applied to obtain the final ranking. With the aggregation procedure, a real value (s) is identified that expresses the agreement, or value, deriving from opting for a given alternative. The ranking of the alternatives is implicitly determined by the transformation of the problem from multi attribute in 'mono-attribute'. For example, a cardinal value is associated with each alternative using the summation of the weighted values of that alternative, or (Voogd, 1983):

$$s_i = \sum_{j=1}^{k} z_{ij} \quad \text{for} \quad i = 1, 2, \ldots, n \tag{5.13}$$

The alternative that maximises the overall preferences of the decision-maker is the one presenting the maximum value s.

There are no substantial criticisms of the value function approach, and in fact, it is often even called the 'exact method' of MADM. The only real problem is the assigning of the value function. This is why, faced with the possibility of using a sophisticated but complicated model, less elaborate but more flexible methods are chosen, such as the two described below.

The hierarchic analysis

The Analytical Hierarchy Process – AHP (Saaty, 1980), as one of the value functions methods, is based on the assumption that the decision-makers may always express their preferences. Therefore, it is possible to represent the relative importance and an overall score to each attribute. AHP is one of the most widely applied MADM methods but also one of the more criticised by specialists.

Within AHP, the valuation decision process is faced through different steps, dividing the overall decision problem into several less complex ones, which have easier solutions. The first phase of the analysis defines: the objective of the choice, the criteria for valuating the achievement of the objective (attributes), and the alternatives amongst which the choice must be made. Moreover, the structure of the decision-maker's preferences must be analysed and formalised in order to evaluate the trade-off between the options. In the next recapitulation phase, the most satisfactory alternative must be decided by ranking on the basis of the criteria determined in the previous phase.

The analysis and recapitulation phases are resolved on the basis of a decomposition principle, pair-wise comparisons and hierarchical composition. The first principle, by means of a breakdown of the problem, leads to the definition of a structure that allows ranking the information of the reciprocal relations of the aspects which influence the final choice. The procedure can be carried out bottom-up or, more often, top-down. The structure of breakdown is organised by specifying, in order, the global objective (super-criterion), valuation criteria (attribute), sub-criteria (parameters) and the alternatives. Figure 5.3 illustrates a four-level hierarchy relating to the choice between three alternatives according to three criteria: 1st level – alternative selection; 2nd level – criteria of choice (attributes); 3rd level – parameters expressing each attribute; 4th level – alternatives.

The decomposition task, as well as providing an overview of all the aspects that may determine a decision, prepares the ground for the subsequent

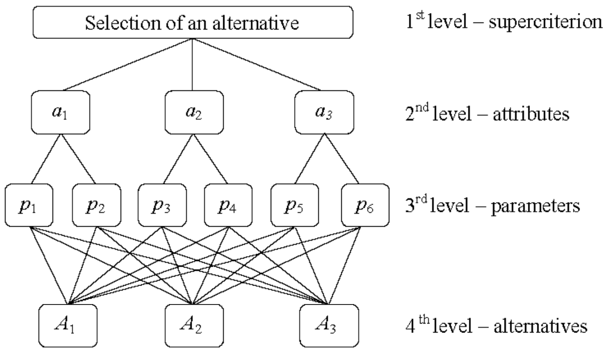

Figure 5.3 The structure of hierarchic analysis

valuation based on the principle of pair-wise comparisons. So the decision maker can concentrate on solving many small, partial problems, and then summarise the global solution, instead of having to consider contemporarily all aspects of the problem.

The global preference of the decision-maker is reached starting from the preferences expressed between the pair-wise comparisons:

1. among the alternatives with reference to one parameter at a time;
2. among the parameters with reference to each attribute;
3. among the attributes with reference to the super-criterion.

The pair-wise comparisons are organised in square matrices, positive and reciprocal, where the numbers represent the decision maker's preference for the element reported in the row regarding the one reported in the column.

The pair-wise comparisons require a suitable scale to represent preferences among alternatives, parameters and attributes. Referring to psychological studies on 'indistinguishability classes', Saaty (1980) proposed a scale of values that can translate qualitative comparisons into quantitative terms. This scale of relative importance covers an interval of values from 1 (equal importance) to 9 (extreme importance) and also defines the reciprocal values of the precedents because, for example, when a preference intensity of 3 is assigned to one aspect compared to another, then the latter has a preference intensity that is the reciprocal of the former (1/3). The scale proposed by Saaty (1/9–9) is not the only one in the literature. Other authors have proposed more restricted (1/5–5) or wider scales (0–100). Starting from the pair-wise comparisons data, eigenvectors are calculated according to which parameters, attributes and alternatives can be ranked at each hierarchical level. The global ranking is obtained through the weighted sum of the scalars representing the rankings of the alternatives with respect to the super criterion (principle of hierarchic composition).

AHP has some limitations: it is highly dependent on the hierarchy assumed, requires a large amount of data (judgements of the decision-maker) and the complete procedure can be quite lengthy. On the other hand, AHP is extremely useful when the decisional problem only allows qualitative evaluations and for defining the vectors of weights to be used by other procedures.

The outranking methods

The outranking methods (for example ELECTRE – ELimination Et Choix TRaduisant la rEalité) have been developed in France (Roy, 1985) and are based on the concept of outranking and concordance/discordance analysis.

These methods are based on a pair-wise comparison between every pair of alternatives being considered, trying to identify when one alternative 'outranks' another, which means that it is at least as good as the other. The objective is to eliminate the alternatives that are dominated by the others.

The concept of outranking (Roy, 1974) implies that one alternative *A* outranks another *B* when, starting from the decision-maker's preferences, enough arguments can be found to say that *A* is at least as good as *B* (concordance), and there are not enough arguments against that (discordance). The different outranking methods differ in the way this definition is formalised. Given two alternatives, there are three possibilities as a result of their comparison: $A_i > A_j$ or $A_i < A_j$: one outranks the other ($A_i \succ A_j$ or $A_i \prec A_j$); $A_i = A_j$: the alternatives are indifferent ($A_i \mathrm{I} A_j$); A_i and A_j are incomparable ($A_i \mathrm{S} A_j$).

Based on this idea, outranking methods generally involve two consecutive steps:

1. construction of an outranking relation of the decision-maker's preferences: defining concordance and discordance indices;
2. exploitation (using assignment procedures) of the outranking relation depending on the nature of the problem to be solved: combining the concordance and discordance indices.

There are several ways to define the concordance and discordance index. The concordance index used in ELECTRE I can be defined as follows:

$$c_{ij} = \sum w_k \quad \text{with} \quad c_{ij} = \left\{k : v_{ki} \geq v_{kj}\right\} \tag{5.14}$$

where k is the set of criteria for which alternative i is equal or preferred to alternative j. The index takes values between 1 and 0: value 1 when A_i is better than A_j for all criteria and value 0, when A_i is worse than A_j for all criteria.

The discordance index is calculated by the maximum difference for which i is dominated by j, divided by the maximum difference in absolute value between performances obtained in i and j.

$$d_{ij} = \frac{\max_{k \in D_{ij}} (v_{kj} - v_{ki})}{[\max (v_{kj} - v_{ki})]} \quad \text{with} \quad D_{ij} = \{ k\text{: } v_{ki} < v_{kj} \} \tag{5.15}$$

If alternative i is better than alternative j on all criteria, the discordance index is 0. When the alternative i is worse than alternative j in all criteria the discordance index is 1.

The information contained in the concordance and discordance matrices can lead to a ranking of the alternatives using different methods. A possible approach to attain a ranking of the alternatives on the basis of concordance and discordance matrices is the 'weak dominance' approach (Colorni and Laniado, 1989). The method is based on the assumption that, in comparing two alternatives A_i and A_j, the first dominates the second in the 'strong' or Paretian sense if c_{ij} = 1 (all aspects favour A_i) and d_{ij} = 0 (no aspect is contrary to A_i). In the case of weak dominance, the Paretian conditions are 'relaxed' through the definition of 'thresholds' of concordance S_c and discordance S_d, respectively. On the basis of these thresholds, A_i weakly dominates A_j if at the same time:

$$c_{ij} \geq S_c \quad \text{and} \quad d_{ij} \leq S_d \tag{5.16}$$

The cardinal and complete ranking of the n alternatives is achieved through a progressive relaxing of the two thresholds, that is reducing S_c and increasing S_d. This ranking does not provide a measurement of the overall performances of the alternative, but makes a judgement on the easiness of excluding it from the analysis, being weakly dominated. ELECTRE I leads to the identification of two subsets of the n alternatives, those which can surely be ignored and those which require further study. It is not therefore a matter of better alternatives, but of alternatives, which remain in play based on some considerations. Within this context the thresholds are intended as the minimum value of satisfaction (S_c) and maximum value of dissatisfaction (S_d) that the decision-maker can tolerate. From application of the two thresholds to the two matrices, ELECTRE I determines a relation of outranking (preference) between the alternatives through a graphic analysis, and from this reaches the identification of incomparable alternatives on which to acquire further information. The version II of the ELECTRE method, based on the same logic, reaches a cardinal ranking of the alternatives (Goicoechea et al., 1982) determining the relationship of outranking based on two pairs of thresholds, one associated with a 'weak' value and one with a 'strong' value. Two outranking graphs (strong and weak) are thus created, from which one final average graph is worked out. This latter is then used to create two rankings of the alternatives, one descending (best vs. worst) and one ascending (worst vs. best), to derive a final ranking that combines both.

ELECTRE I and II are based on the idea of 'true criteria', which implies that any differences in performance between two criteria are considered as differences in preferences. However, it is not sometimes so easy to determine clearly the preferences when two performances are very close. For that purpose ELECTRE III uses 'quasi-criteria', defining two thresholds (preference and indifference) introducing the concept of 'weak' and 'strong' preferences. As in ELECTRE II, ELECTRE III is used for ranking problems, but in this more sophisticated method some fuzzy information is introduced by the definition of the preference and indifference thresholds when comparing alternatives against a specific attribute. The concordance and discordance indices are also based on this parameter, obtaining two complete pre-orders, ending in a weighted ranking of the alternatives.

Based on ELECTRE III, other versions have been developed for challenging specific problems. ELECTRE TRI is used for classification problems where the objective is to assign the alternatives in more than three categories (acceptable, indeterminate, and unacceptable). ELECTRE IV has been developed for specific situations where the decision-maker is unable or does not wish to specify the criteria weights. This method uses the same procedure as ELECTRE III, but the outranking is defined by referring directly to the performances of the alternatives (Belton and Stewart, 2002).

Another popular outranking method is PROMETHEE. This method (Brans and Vincke, 1985), like ELECTRE III, is based on weighted outranking relations. The differences between performances for each criteria are measured using different preference functions which describe the intensity of the preference of an alternative *a* over alternative *b*.

The PROMETHEE method can be described in the following steps. The first step consists of building the evaluation matrix by defining the alternatives and the criteria against which they will be evaluated (the criteria can be measured in different units and scales). The next step involves the specification of the preference structure (by introducing generalised criteria) to remove scaling effects. From this point, PROMETHEE specifies the dominance relation by building a multicriteria preference index that represents the strength of the assumption that one alternative is preferred to the others and creating an associated outranking graph that represents the weakness of the assumption.

$$\pi(a,b) = \sum_{j=1}^{n} w_j P_j(a,b) \tag{5.17}$$

This dominance index is summarised in two index flows that represent both how an alternative is preferred over the others and how the others are preferred over this alternative

$$\phi^+(a) = \sum_{b \in A} \pi(a,b) \text{ inflows: how } a \text{ is preferred over others} \tag{5.18}$$

$$\phi^-(a) = \sum_{b \in A} \pi(a,b) \text{ outflows: how the others are preferred over } a \tag{5.19}$$

The exploitation for decisional aid differs depending on the version of the method. PROMETHEE I provides a partial ranking of the alternatives where the best one has ϕ^+ and the lower ϕ^-. In PROMETHEE II a complete pre-order is derived from the net flow of each alternative (inflows-outflows) $\phi(a) = \phi^+(a) - \phi^-(a)$. Other more sophisticated versions have been developed (Promethee III, Promethee IV and Promethee V) to tackle more complicated problems, in particular those with a stochastic component.

5.2.3 Fuzzy Sets

One of the main problems in applying MCDM in integrated water resources management is the quality of information available. Sometimes the effects over a long period of WRM cannot be identified and this makes it more difficult to analyse the consequences, such as the environmental effects of building a dam. Many hydrological models have been developed to simulate certain aspects of water problems but in general they are too rough to represent all the effects of a certain decision. In integrated water resources management, the uncertainty and vagueness of the information has to be taken into account. On the other hand, decision-makers normally encounter a lot of problems to identify precisely their preferences. Fuzzy sets is a way to model vagueness and imprecision.

The fuzzy set, introduced by Zadeh (1965), cannot be considered as model in itself, but as a tool that, in given circumstances, could be very helpful in MCDM. The fuzzy approach underlies the fact that, in the real world, decision-makers cannot normally define their preferences within a precise (crisp) logic, and provide an explicit way to represent the vagueness of the decision-maker's mind and real word aspects.

Formally a crisp set $A \subset X$, can be represented in terms of a membership function $I_A(x)$, such that for any object $x \in X$, $I_A(x) = 1$ if $x \in A$, otherwise $I_A(x)=0$. Given the set of alternatives A that dominates an alternative b, for $x \in X$, the alternatives are $x \in A$ or $x \notin A$.

The fuzzy set approach replaces the indictor function of a set by a membership function that represents up to what level we can say that $x \in A$, what is $0 \leq \mu_A(x) \leq 1$. Normally in the real world when we have to establish our preferences, we are more fuzzy than 'crisp' in our judgements. When we use qualitative variables, the outranking concept, establishing goals or aspiration levels of the value function, the use of fuzzy sets is very helpful. All the most common MCDM approaches, such as AHP, ELECTRE, Goal Programming, and so on, have their fuzzy version (Fuller and Carlsson, 1996).

5.3 A SURVEY OF MULTIPLE CRITERIA DECISION MAKING APPLICATIONS IN WATER RESOURCES MANAGEMENT

In this survey, we present the main contributions on the application of MCDM techniques in the last 10 years in the most important journals related with MCDM and WRM. This study is not meant to be exhaustive, and just a small number of articles have been analyzed. For that reason other interesting papers have been omitted in this analysis. In any case, our objective is to present a general outlook of the last applications of MCDM in the field of WRM, evidencing the integration aspects. A summary of the articles analyzed is presented in the annex.

In MCDM there is not a common framework regarding the models to apply to support the decision-making process. Different researchers with different backgrounds use the multicriteria methods according to their needs in alternative ways. In addition, different types of problems are faced under different circumstances. Many MCDM techniques and applications have been developed in the field of water resources management. Earlier examples can be found in Haimes et al. (1975), where the use of the surrogate worth trade-off method as a decision tool in water resources planning is discussed, Cohon and Marks (1975) who presented an early review of multiobjective programming techniques, and in Goicoechea et al. (1982).

In WRM, a broad type of problem can be encountered. The different nature of the problems motivates the different MCDM methodologies used and it is difficult to find the most suitable technique for a specific problem or type of problems. In fact, there are no strict relationships between methods and problems. Furthermore, the selection of MCDM techniques depends also on the availability of information and their quality.

Regarding the main problems faced in the different analyses, water scarcity is dominant in the survey. Water scarcity is one of the main problems currently and, moreover in the Mediterranean area and developing countries, especially in the Middle East where the low levels of water resources combined with high rates of population increase become serious constraints to development. However, applications normally consider more than a single issue because of the interrelation with the other major problems related with water. In that sense Al-Shemmeri et al. (1997) and Jaber and Mohsen (2001) face the problem of water scarcity management in Jordan from an integrated perspective. Other papers also present problems related to water quality. Quality in surface water affected by agriculture are analysed by Heilman et al. (1997) or affected by wastewater planning in Kholghi (2001). Shafike et al. (1992) describe problems in groundwater contamination management and Woldt and Bogardi (1992) consider groundwater monitoring system design. Other examples in flood control can be seen in Tkach and Simonovich (1997) and Janssen et al. (2005), where the MCDM are combined with GIS tools, or in transboundary contexts as in Özelkan and Duckstein (1996).

An interesting question that arises from the survey is the fact that most of the analysis attempts to assist decision makers from a strategic perspective because of the evolution of the water problem issues in a global perspective. MCDM, initially developed for operational analysis, has evolved also to become a very useful tool in strategic planning and management. Specific examples in river basin planning can be found in Pouwels et al. (1995) and Hamalainen et al. (2001). In some problems, normally at operative level, only quantitative information derived from technical data was analyzed, also using hydrological models (Prathapar et al., 1997). In other cases, mainly at strategic level, politicians and other non-technical decision makers need to

Table 5.4 Distribution of the papers by type of problem

Type of problem	Paper	%
Water scarcity	17	40
River basin management	8	19
Reservoir management	8	19
Water quality	6	14
Flood control	1	2
Power generation	1	2
Transboundary	1	2
Total	*42*	*100*

express their preferences and their points of view using qualitative information as well. At a strategic level, some non-commensurable criteria were also found using qualitative data in order to assess the impact of each alternative against each criterion, as in De Marchi et al. (2000) where the impact of the different policy options presented in the analysis are constructed based on qualitative scales.

In most of the papers the feasible set of solutions is discrete. Some authors have used a combination of methodologies starting from a continuous set of alternatives to develop a discrete set to be analyzed in a second step, as in Ko et al. (1992) and Ridgley et al. (1997) where continuous methods are applied to identify non-dominated solutions and then discrete methods are used to select the preferred one. Regarding the type of context where MCDM methods were applied, most of the problems deal with the selection of the best alternative from predefined courses of action or a ranking of them. For example in reservoir management (Mahmoud et al., 2000) the choice of different management alternatives is made from a list of alternatives previously selected regarding technical feasibility. Continuous applications include Prathapar et al. (1997) and Bazzani et al. (2005) where the objective is to identify the optimal combination of crops regarding their water consumption, Heilman (1997) where the effects of the quality of pollutants and economic returns are evaluated on different management systems, and Lee and Wen (1997) where the optimal solution is derived from the pollution assimilative capacity and the cost of treatment of wastewater.

One of the main problems in applying MCDM techniques is to identify a feasible set of alternatives as was explained in previous section, for example in water allocation where the alternatives are implicitly defined as a combination of decision variables subjected to a certain number of constraints. In this case, the objective of the analysis would be the selection of the best alternative from an infinite range of possibilities. In IWRM, considering water as a scarce resource, the main constraints are the quantity of water for different purposes and the quality of water under standards depending on the final use of the water. This kind of analysis is usually done at operational level; examples can be found in Harboe (1992) and Ko et al. (1992) related to reservoir management, and Shafike et al. (1992) and Woldt

Table 5.5 Distribution of the papers by decision context

Decision context	Paper	%
Strategic	30	71
Operational	12	29
Total	*42*	*100*

and Bogardi (1992) in groundwater management.

The identification of a set of alternatives could be seen not only as a final analysis, but as a preliminary step for the evaluation analysis. In some examples (Ko et al., 1992; Gupta et al., 2000) both type of analysis have been done, where a set of alternatives, subjected to constraints of quantity or environmental protection, has been identified in a first step. In the second step, the selection of the best alternative from those defined in the previous one is included.

Following the classification of MCDM analysis proposed in a previous section of this chapter, both main categories of methods, MODM and MADM, are used in the same proportion. Moreover, several articles present comparative studies of the different methods with the aim of identifying the methodology that satisfies the specific characteristics of the problems presented. Some papers have emphasized the problem to find the appropriate technique to be applied in different cases as in water scarcity in Raju and Pillai (1999) where five different MCDM techniques were used to rank alternative policies in an irrigation area in Spain, reservoir management in Mahmoud et al. (2002) where also five different multicriteria evaluation methods are compared for fish migration in the Red Bluff diversion dam, or river basin planning in the Flumen Monegros irrigation area in Spain (Raju et al., 2000).

Most of the MODM methods, that were initially developed to be applied in continuous problems, have been adapted for discrete problems. Within the MODM methods, Compromise Programming is the most widely used (Shafike et al., 1992), sometimes combined with fuzzy sets (Woldt and Bogardi, 1992).

Table 5.6 Distribution of the papers by type of set of alternatives

Set of alternatives	Paper	%
Discrete	29	69
Continuous	11	26
Mixed	2	5
Total	*42*	*100*

Table 5.7 Distribution of the applications by type of methods

Type of method	Applications	%
MODM	28	47
MADM	32	53
Total	*60*	*100*

The MADM techniques were applied mainly at strategic level where some qualitative information was required. Examples can be found in Roy et al. (1992) with the analysis of the priority order in the use of a new water supply system. Within the MADM, there are four techniques that have been used in higher percentage: Value Functions, AHP , ELECTRE and PROMETHEE.
Within the MADM methods, PROMETHEE is the most used (31 percent), followed by AHP and then ELECTRE. All of them have available computer software that facilitates their use. A good example of PROMETHEE application can be found in Al-Shemmeri et al. (1997) where the decision making process is presented using a combination of techniques in the identification of the alternatives in strategic planning in Jordan. Other examples are Abu-Taleb et al. (1995) also in Jordan and Al-Kloub et al. (1997). Within other outranking applications different versions of ELECTRE are applied like ELECTRE I-II (Harboe, 1992), ELECTRE III (Roy et al., 1992, Bella et al., 1996) or ELECTRE-TRI (Raju et al., 2000). Some other MADM like AHP are all wide used (Qureshi et al., 1999; Jaber et al., 2001; Tongplew et al., 2003).

In all the cases analysed, the decision makers were always associated with public agencies. The problem of stakeholders' involvement has been studied in depth in some papers, as in De Marchi et al. (2000) where the preferences of the various actors involved are analysed in a municipality problem in Sicily, and in Hamalainen et al. (2001) where a framework for support of a multi-stakeholder decision process is described.

Table 5.8 Distribution of the applications by MODM methods

MODM method	Applications	%
MOLP	7	25
Compromise Programming	13	46
Goal Programming	8	29
Total	*28*	*100*

Table 5.9 Distribution of the applications by MADM methods

MADM method	Applications	%
Value functions	6	19
AHP	9	28
Electre	7	22
Promethee	10	31
Total	*32*	*100*

5.4 CONCLUSION

Since the first developments in Operations Research at the beginning of the last century, several MCDM methods have been developed and applied to water-related problems. In general terms, it is possible to affirm that integrated water resources management can be considered as a multicriteria decision making problem itself. The first applications to water management in the 1970s were oriented to operational decision contexts with highly structured problems to be solved by just one decision-maker. The evolution towards a more integrated approach in water management has imposed an evolution of the methods to assess water measures management under this new paradigm.

The use of MCDM has now been extended from operational to strategic level. At the strategic level, it becomes more difficult to find a well-defined problem and most of the criteria are non-commensurable. For this reason, methods applied also need to be able to take qualitative data into account.

A great number of multicriteria methods have been applied over the last years in different situations and for different purposes in the field of integrated water resources management. The strongest argument for use of the methods was their ability to give better comprehension of the water problems and the possibility to explore conflicting points of view. It seems that recently more effort has been put into the application of existing methods than into the development of new ones. In general, many achievements have been obtained from these applications but also some problems have arisen.

The first group of problems relates to the information available. Some contributions tried to overcome the merely technical data perspective by including socio-economic aspects in a more integrated manner. Nevertheless, the lack of suitable information for the evaluation process seems, at the moment, to be the most relevant problem, sometimes because of the randomness of future situations or the incomplete knowledge of experts. In general, uncertainty about the possible effects of alternative courses of action is also very high. For this reason, several applications have included the use of fuzzy sets in their applications.

The second group of problems refers to the transparency of the decision-making process in IWRM. Decision-makers, normally politicians without a quantitative background, have difficulties accepting complicated methods even if they have a user-friendly software interface. If the algorithms used are too complicated to be understood by the decision maker, the decision making process is seen as a black box, and the results can create some distrust and rejection within a decision group.

Thirdly, public administrations, whose responsibility is to make decisions in water management, are not experienced in applying this type of MCDM methodologies. Sometimes thorough studies about alternatives within complex water resources problems are required, but this raises conflict with restrictions in cost and time that characterize administrative procedures. The public administration is conscious that the mono-criterion approach is not sufficient anymore to assess water resources problems, but on the other hand applying multicriteria decision analysis in the real world can become difficult from the institutional point of view.

Finally, decision-making problems normally imply the existence of a group of decision-makers with different conflicting points of view. Hence, Group Decision Making is becoming of more and more interest along with methodologies that allow a more interactive and collaborative analyses of the alternatives, as well as the risk associated with each of them.

The trend in the last few years seems to emphasize the use of less complex MCDM methods instead of more sophisticated ones. The reason is that, in most cases, integrated water resources management implies public decisions at the strategic level that normally are undertaken by politicians without a technical background, neither in water resources nor in multicriteria methods. The less complex MCDM methods can be used in this situation as they facilitate a higher level of transparency in the process.

In any case, a comprehensive framework for analyzing policies and prioritizing options to guide the decision-making process around integrated water resources management is needed. This framework needs to highlight the importance of structuring the problems, the use of understandable technical data combined with value judgments with an active participation of all the actors involved in the whole process.

NOTES

1. See chapter 1 for a comprehensive discussion on policy issues related to water management.
2. A solution is Pareto – efficient if is not possible to identify an alternative solution which, within the set of those feasible, along with an improvement with respect to one objective, would not also imply a worsening of at least one other (Romero, 1991).
3. Although the terms 'value' and 'utility' are frequently used as synonyms (as in this chapter), it should be specified that, more accurately (Keeney and Raiffa, 1976), value functions are used for deterministic data, while utility functions are used in stochastic situations.

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ANNEX

n.	Authors	Year	Problem	Strategic	Operational	Fuzzy	MODM: MOLP	MODM: Compr. Prog.	MODM: Goal Prog.	MADM: Value Function	MADM: AHP	MADM: Promethee	MADM: ELECTRE
1	Roy, B., Slowinski, R., Treichel, W.	1992	WATER SCARSITY	✓	·	·	·	·	·	·	·	·	✓
2	Shafike, N.G., Duckstein, L., Maddock, T.	1992	GROUNDWATER QUALITY	·	✓	·	·	✓	·	·	·	·	✓
3	Woldt, W., Bogardi, I.	1992	GROUNDWATER QUALITY	·	✓	✓	·	✓	·	·	·	·	·
4	Bogardi, I., Duckstein, L.	1992	RESERVOIR MANAGEMENT	·	✓	·	·	·	·	·	·	·	·
5	Goicoechea, A., Srakhiv, E.Z., Li. F.	1992	WATER SCARSITY	✓	·	·	·	·	·	·	✓	·	✓
6	Harboe, R.	1992	RESERVOIR MANAGEMENT	·	✓	·	·	✓	✓	·	·	·	✓
7	Ko, S.K., Fontane, D.G., Labadie, J.W.	1992	RESERVOIR MANAGEMENT	·	✓	·	·	✓	✓	·	·	·	·
8	Chang, N., Wen, C.G. Wu, S.L.	1995	RESERVOIR PLANNING	✓	·	·	·	✓	·	·	·	·	·
9	Pouwels, I.H.M., Wind, H.G., Witter, V.J.	1995	RIVER BASIN PLANNING	✓	·	·	·	·	·	✓	·	·	·
10	Abu-Taleb, M.F., Mareschal, B.	1995	WATER SCARSITY	✓	·	·	·	·	·	·	·	✓	·
11	Chang, N., Wen, C.G., Chen, Y.L., Yong, Y.C.	1996	RESERVOIR PLANNING	✓	·	✓	✓	·	·	·	·	·	·
12	Özelkan, E.C., Duckstein, L.	1996	TRANSBOUNDARY	✓	·	·	·	✓	·	·	·	✓	·
13	Bella, A., Duckstein, L., Szidarovszky, F.	1996	WATER SCARSITY	✓	·	·	·	✓	·	·	·	·	✓
14	Al-Shemmeri, T. , Al-Kloub, T., Pearman, A.	1997	WATER SCARSITY	✓	·	·	·	·	·	·	·	✓	·
15	Prathapar, S.A., Meyer, W.S., Madden, J.C.	1997	GROUNDWATER SCARSITY	·	✓	·	✓	·	·	·	·	·	·

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							MODM			MADM			
n.	Authors	Year	Problem	Strategic	Operational	Fuzzy	MOLP	Compr. Prog.	Goal Prog.	Value Function	AHP	Promethee	ELECTRE
16	Heilman, P., Yakowitz, D.S., Lane, L.J.	1997	WATER QUALITY	·	✓	·	✓	·	·	·	·	·	·
17	Lee, C., Wen, C.	1997	WATER QUALITY	·	✓	✓	·	·	✓	·	·	·	·
18	Ridgley, M., Penn, D.C., Tran, L.	1997	RIVER BASIN PLANNING	✓	·	·	·	·	✓	·	✓	·	·
19	Tkach, R.J., Simonovic, S.P.	1997	FLOOD CONTROL	✓	·	·	·	✓	·	·	·	·	·
20	Al-Kloub, B., Al-Shemmeri, T., Pearman, A.	1997	WATER SCARSITY	✓	·	·	·	·	·	·	·	✓	·
21	Raj, P.A., Kuma, D.N.	1998	RIVER BASIN PLANNING	✓	·	✓	✓	·	·	·	·	·	·
22	Bernel, J., Rodriguez-Ocaña, A.	1998	WATER SCARSITY	✓	·	·	·	·	✓	·	·	·	·
23	Raju, S., Pillai, C.R.S.	1999	RIVER BASIN PLANNING	✓	·	·	·	✓	·	·	✓	✓	✓
24	Qureshi, M.E., Harrison, S.R., Wegener, M.K.	1999	RIVER BASIN PLANNING	✓	·	·	·	·	·	✓	✓	·	·
25	Arondel, C., Girardin, P.	2000	GROUNDWATER QUALITY	·	✓	·	·	·	·	·	·	·	✓
26	Raju, S., Duckstein, L., Arondel, C.	2000	WATER SCARSITY	✓	·	·	·	✓	·	·	·	✓	✓
27	Bender, M.J., Simonovic, S.P.	2000	RIVER BASIN PLANNING	✓	·	✓	·	✓	·	·	·	·	✓
28	Gupta, A.P. , Harboe, R., Tabucanon, M.T.	2000	WATER SCARSITY	·	✓	✓	✓	·	·	✓	·	·	·
29	De Marchi, B. , Funtowicz, S.O., Lo Cascio, S., Munda, G.	2000	WATER SCARSITY	✓	·	✓	·	·	·	·	·	·	·
30	Gomez-Limon, J.A., Berbel, J.	2000	WATER SCARSITY	✓	·	·	·	·	✓	·	·	·	·

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n.	Authors	Year	Problem	Strategic	Operational	Fuzzy	MODM: MOLP	MODM: Compr. Prog.	MODM: Goal Prog.	MADM: Value Function	MADM: AHP	MADM: Promethee	MADM: ELECTRE
31	Lee, Y.W., Bogardi, I., Kim, J.H.	2000	WATER SCARSITY	·	✓	✓	·	✓	·	·	·	·	·
32	Jaber, J.O., Mohsen, M.S.	2001	WATER SCARSITY	✓	·	·	·	·	·	·	✓	·	·
33	Hamalainen, R.P., Kettunen, E., Marttunen, M., Ehtano, H.	2001	RIVER BASIN PLANNING	✓	·	·	·	·	·	·	✓	·	·
34	Nayak, R.C., Panda, R.K.	2001	WATER SCARSITY	✓	·	✓	✓	·	✓	·	·	·	·
35	Dhillon, J.S., Parti, S.C., Kothari, D.P.	2001	POWER PRODUCTION	✓	·	✓	✓	·	·	·	·	·	·
36	Qureshi, M.E., Harrison, S.R.	2001	RIVER BASIN PLANNING	·	✓	·	·	·	·	·	✓	·	·
37	Kholghi, M.	2001	WATER QUALITY	✓	·	·	·	·	·	✓	·	·	·
38	Mahmoud, M.R., Fahmy, H. Labadie, J.W.	2002	RESERVOIR MANAGEMENT	✓	·	·	·	✓	·	✓	✓	✓	✓
39	Cain, J.D., Jinapala, K., Makin, I.W., Somaratna, P.G., Ariyaratna, B.R., Perera, L.R.	2003	WATER SCARSITY	✓	·	·	·	·	·	·	·	·	·
40	Thongplew, K., Varawoot, V.	2003	RESERVOIR MANAGEMENT	✓	·	·	·	·	·	·	✓	·	·
41	Janssen, R., Goosen, H., Verhoeven, M.L., Verhoeven, J.T.A., Omtzgt, A.Q,A., Maltby, E.	2005	RESERVOIR MANAGEMENT	✓	·	·	·	·	·	✓	·	·	·
42	Bazzani, G.M., Di Pasquale, S., Gallerani, V., Moranti, S., Raggi, M., Viaggi, D.	2005	WATER SCARSITY	·	✓	·	·	·	✓	·	·	·	·

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4.4 WATER MANAGEMENT, PUBLIC PARTICIPATION AND DECISION SUPPORT SYSTEMS: THE MULINO APPROACH

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Water Management, Public Participation and Decision Support Systems: the MULINO Approach

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Abstract: One of the main issues in the environmental decision making field is the necessity, sometimes obligation imposed by the legislation, to communicate the decision process and make it more comprehensible. In other words, the objective is to increase the transparency of the decision making available all the relevant information related to the decision process for all interested actors. For this reason, many tools have been developed over the last decades: indicators, conceptual frameworks, and impact assessment studies are examples. However, many of these tools try to represent the environmental situation or hypothetical future states without any explicit reference to how decisions are taken or should be taken. Some environmental decision support systems are developed for that specific purpose. One critical point in the development of such a DSS is the connection between the representation of reality and the elicitation of preferences of the decision makers. Moreover, environmental decision making requires that preferences and value judgments refer to technical and scientific information that is not easy to communicate to people in general. The European project, MULINO (contract no. EVK1-2000-22089), completed at the end of 2003, has focused on connecting environmental tools and decision support methods, by combining the DPSIR approach with multicriteria analysis methods in a decision support system called mDSS. The DPSIR is a conceptual framework developed by the EEA through which environmental problems can be structured and explored in a heuristic way. This process may be undertaken in a group (e.g. the decision makers and the stakeholders together) using the framework to structure discussion between those who decide and those who are involved in the problem. In this paper, we describe the MULINO approach, focusing on the experience gained with the end users involved in the project in applying the mDSS software. In particular, we present the use of the DPSIR approach to structure and communicate their decision context and the potentials for stakeholders' involvement.

Keywords**:** Environmental tools, decision support system, DPSIR, Water Framework Directive

1. INTRODUCTION

Since 1992 and the signing of the Rio Declaration on Environment and Development and Agenda 21, where a plan of action to achieve the sustainable development into the 21st Century was set out, the concepts of public participation and stakeholder involvement have had a growing influence on policy formation and decision making processes. There are still large knowledge gaps and culture clashes, which make the realization of participatory processes problematic for most governing bodies. The increase in the number of actors, both public and private, affirms the need for capacity building to define mediation techniques and co-operative approaches appropriate for active stakeholder involvement. At the present time however, the situation is complicated for authorities that are obliged to execute participative planning procedures.

Like environmental planning in general, Integrated Water Resources Management (IWRM) is usually characterized by the involvement of numerous decision-makers operating at different levels and the large number of stakeholders with conflicting preferences and different value judgments [Lahdelma *et al.* 2000)] This makes the development of policy implementation strategies and decision making in the context of IWRM a very complex issue, also because it requires a broader integration with other sectors such as environment, energy, industry, agriculture, tourism.

Adequate methodologies and tools become therefore necessary in order to measure how a specific policy meets the objectives established by the various actors, to identify and understand the possible conflicts that may arise between these actors and, finally, to design possible paths and courses of action to arrive at a sustainable solution. The need for adequate methodologies and tools calls for a strong role to be played by science and research. The commitments made by the scientific community of the 2002 World Summit on Sustainable Development was in fact to make science more policy relevant [ICSU, 2002].

Environmental problems and in particular those related to water resources are usually very complex and therefore the decision making process requires high background in environmental, economic and social disciplines. Moreover, there is quite often a dramatic gap between those who analyse and provide disciplinary expertises and those who decide, not only in the knowledge but also in the aims and the way of thinking and the language [Luiten, 1999].

The European Water Framework Directive (WFD) [EC, 2000] specifically addresses public information and consultation in Article 14. It is obligatory for the Member States to involve the public in the implementation of the Directive by publishing specific information relevant to the River Basin Plans and to be open to comments made by the public about the planning process. Member States are also to encourage the active involvement of all interested parties, which would require more than the publication of information.

The WFD is laying the groundwork for social sustainability by establishing public involvement in planning procedures as common practice. Even if the level of obligatory participation is the most basic, for some European countries this is a necessary first step as it may be that citizens have had no legitimate role in the management of water before.

The participation of a range of stakeholders in the planning process might take on a number of forms, including public forums, focus groups, and the use of specialized workshop techniques or software for group decision making. All of these alternatives however have social implications for the understanding of how rights and responsibilities are distributed with society.

The amount of decision control that is devolved to the community for the management of natural resources and the role that public authorities play determine to a great extent the socio-political character of a society. For some Member States, Article 14 may represent a "business as usual" scenario in that this kind of information exchange between the citizens and the public authorities already takes place in some form. This means that the communication infrastructures are already in place and that both individuals and stakeholder groups expect the opportunity to comment on planning proposals. For other Member States, it is possible that there is little history of such exchanges, making the implementation of this Article more difficult. It may be costly to establish new lines of communication and the facilities for collecting and recording public opinions, and such procedures may be incompatible with current planning approaches. Moreover, there may be resistance to what may seem like a step towards a redistribution of power that threatens the freedom of individuals or organizations to make decisions in a non-transparent way.

2. DECISION MAKING IN IWRM

The role of public participation in IWRM

In a decision making process, it is possible to identify people, groups or institutions that can play a meaningful role in the final decision. In general, we can classify these main actors as decision makers, people and groups affected, and analysts. But normally in the real life, not all of these actors are always involved in the decision making process.

The decision maker is situated in the centre of the decision making process and is the one who has the institutional power and responsibility to select and implement a solution for a specific problem. People affected are all those whom will be influenced by the consequences of the solution adopted and implemented by the decision maker. The analyst is the person/group that helps and guides the decision maker to analyse and represent their preference structures and those from other interested groups.

One of the main issues in the field of environmental decision making is the need, sometimes the obligation imposed by the legislation, to communicate the decision process and make it more comprehensible and transparent. For the reasons described above, there is no doubt that public participation has become a major issue in IWRM. In order to facilitate the active involvement of all the stakeholders in water decision problems there is a challenge that has to be faced: the integration of scientific knowledge and public participation. This is not an easy task.

Facing water problems, decision makers find public participation important for various reasons, first of all because it is required by legislation (e.g. the WFD). Moreover, decision makers are responsible of the selected decision and also its acceptance, for which public participation is essential. Nevertheless, major problems in IWRM like the lack of available information, the uncertainty about future effects or the incomplete knowledge of experts, create more difficulties on obtaining these goals. Decsion makers have in general, little experience in sustainable water management. Because of this inexperience and the uncertainty inherent to these decision problems, public preferences need to be included in a more direct way by sharing part of the responsibility and trying to find compromise solutions that facilitate acceptance.

Another reason for public participation is the role that water plays in our society. Water can be considered an important primary good, and is closely related to social and economic development. In addition, environmental sustainability is critical. One possibility to better understand and implement common interests is public participation.

In contrast, some disadvantages have to be also taken into account and to be solved. Public administrations, that normally have the responsibility to make decisions in IWRM, are not always experienced applying public participation. In addition, the public involvement could represent a problem to the restrictions in cost and time that normally guides administrative procedures.

Integration of public participation in IWRM

Once the crucial importance of the public participation in the decision making process in IWRM has been recognized, the next step must be to clarify the way public participation, decision making and science knowledge can be integrated. For this integration, all the meaningful information has to be collected, structured and presented in an understandable way to help decision makers to integrate all the actors involved in the decision making process and all the scientific knowledge available. Several decision support systems have been developed in the last years to satisfy this need, for specific water resource planing activities such as prevention of water shortages (drought), surpluses (floods) and water impairment (pollution). Examples of such DSS are WATERWARE [Fedra, 1994], [Jamieson and Fedra, 1996a; Jamieson and Fedra, 1996b], AQUATOOL [Andreu et al., 1996], NELUP [O'Callaghan, 1995], [Dunn et al., 1996], FLOODSS [Catelli et al., 1998], DSSIPM [da Silva et al., 2001], STEEL-GDSS [Ostrowski, 1997].

A decision making process normally implies the following steps (Figure 1): identification of the alternatives that can solve the problem; the selection of the criteria against which alternatives are going to be compared; the estimation of the performances of the alternatives related to the criteria; the selection of the aggregation procedures of the information derived from performances and the relative importance of the criteria in the final decision.

As described above, decision makers do not have information enough about the perceptions of the problems by the society due to the complexity of water problems. The role of public participation at this level could be helpful to identify the main relevant criteria and their societal targets in the decision process. However, the general public also has problems to identify these criteria, normally represented by physical, social and economic issues, out of specific and comprehensive data. For this reason, indicators available from scientific knowledge can provide crucial guidance for decision-making. They can translate physical and social science knowledge into manageable units of information that can facilitate the public participation in the decision-making process. Indicators may provide a means of measuring, monitoring and reporting on progress towards societal goals (e.g. quality of life, welfare, etc.) . It may be thus possible to assess effectiveness of policy measures by analysing causality between a policy and its impacts in terms of changes in indicator values. Still, getting the public to understand such scientific information is daunting.

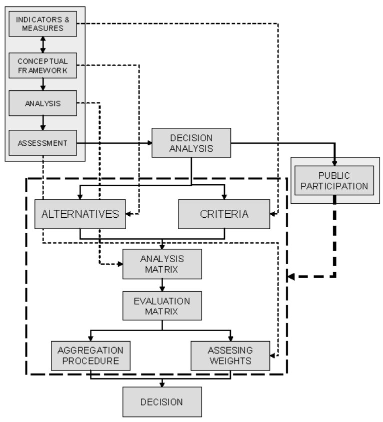

Figure 1: Knowledge and decision making for IWRM and sustainable development.

Using conceptual frameworks for public

participation

In order to assess whether policies will be working and to fine-tune them in order to reach the ultimate objective, conceptual frameworks are needed. They facilitate the understanding and exchange of information between policy-makers, stakeholders and technical and scientific support.

Public participation could be also involved in the identification of alternatives. But as political decision makers, they need an overall view of the problems. Frameworks that structure collections of indicators and that communicate their application are being developed, at different analytical levels. For the purposes of IWRM, the frameworks for environmental reporting and monitoring may play a positive role. A relevant example is the DPSIR framework (Driving Force – Pressure – State – Impact – Response), developed by European institutions: the EEA and Eurostat [EA, 1999]. This conceptual framework applied to water management is reported in Figure 2 and presented in more detail.

The DPSIR framework is widely used to structure indicators to allow for a holistic and multi-dimensional view of causal relationships in human-environmental systems. Within the DPSIR framework, indicators are used to assess different states of the interaction between man and his environment. The integrated set of indicators is assumed to simplify for the decision-maker and stakeholders the comprehension of the complex interlinkages between multisectoral human action and the coevolutions of ecological, economical and social states.

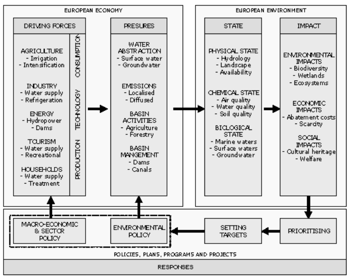

Figure 2: DPSIR framework applied to water management [adapted from NERI 1997]

As the example shown in Figure 2, conceptual frameworks could help to identify the decision level related with the specific problem and the range of alternatives that could solve it. This conceptual framework allows to have a common understanding of the problem that is a basic step for an effective decision making process and the basis to propose.

In order to obtain the analysis matrix, decision makers have to reflect their value judgements and preferences by the public utility functions. As in the selection of the criteria, decision makers have the problem of lack of information about this point. That is why at this point public participation is needed. By public participation, asking directly all the actors involved in the decision process about their individual preferences, the general form of the public utility function for each criterion previously selected can be obtained.

Public participation is also needed in the selection of the aggregation procedure. Several aggregation methods are available and the analyst should help to select the most suitable method based on the preferences of the actors involved and, depending on the problem faced. Not all the problems are the same and each specific context requires a specific method.

The last point where public participation could play an important role in the decision process is in the assessing of weights to aggregate all the information. In this step, some conflict may arise because of the different interest of the actors involved in the process. Public participation could increase the acceptance of the final decisions, making clear the individual preferences and giving the basis for possible compromise solutions

We believe that public participation could play an important role in the decision making process related to IWRM, where the environmental tools could be also helpful. There is not a consensus about the involvement of public in the decision process. Different levels of public participation have their advantages and disadvantages and they must be clearly established for each particular type of problem.

3. MULINO DSS

A methodological approach and a DSS tool have been developed within the MULINO Project [Giupponi et al., 2004] for integrating the four steps described above, in the context of decision making in IWRM. The next paragraphs describe how indicators and indices are managed within a conceptual framework and how they can be utilized in specific forms of analysis, for the implementation of IWRM principles in decision making.

The conceptual framework and the role and management of indicators

Within the IWRM context the initial task of decision makers is usually that of acquiring or consolidating knowledge about the territory they manage by collecting information about human activities and their relationships with the environmental systems. This may be based upon the identification of suitable indicators, which may provide concise quantification and temporal monitoring of the main human and environmental variables interacting within the given territorial systems, typically a river basin.

The whole informative and decision process should be then formalized within a conceptual network, in this case based upon the DPSIR approach. In such a conceptual framework related to natural resources management and, in particular to IWRM, the Impacts describe the existing problems arising from the change detected in State variables, which affects their economic value, environmental function and social role (either in quantitative, or qualitative terms), thus allowing to support decision making within the perspective of sustainable development. Such a conceptual structure can support the establishment of new lines of communication between different actors and help to facilitate the collection and recording of public opinions..

The level of the responses has to be related to the magnitude of the impacts. These different responses need different planning processes and different decision makers could be involved. The different planning levels could be policies, plans, programs and projects, from macro to micro level. A crucial aspect of implementing the DPSIR approach in a methodology for implementing the principles of IWRM in decision making is the transformation of a static reporting scheme in a dynamic framework for integrated analysis and assessment. The next two paragraphs present how Integrated Assessment Modelling (IAM) combined with a Multi-Criteria Analysis (MCA) methods can provide methodological support for analysis and assessment procedures.

Analysis methods: modelling and evaluation

The implementation of IAM in the DPSIR framework is approached in the proposed methodology by focusing on the DPS part of the conceptual framework. These three elements were considered as explicit formalizations of driving variables, model parameters and outputs, respectively. In the case of water pollution models, for instance, D's represent the forcing variables ruling the behaviour of the simulated system (i.e. the catchment). P's may be represented by parameters that express the rate of pollution processes and S's are the output variables quantifying the dynamic evolution of the catchment system, as affected by the considered pollution sources and processes. Integration of models may occur at various levels and in different ways and thus relationships along the chains could be expressed by parallel one-to-one flows, or one-to-many (e.g. one activity affecting various environmental compartments), or many-to-one (e.g. various sectors affecting the same environmental indicator), or even many-to-many, in the case of multi-sector integrated models.

In the context of environmental decision making, IAM can support the identification of the correct Responses by providing sets of indicator values. These values are derived from subsequent simulation runs in which model(s) are parameterised to represent the expected consequences of a set of possible alternative responses. The development of a set of evaluation indices is a crucial step. It should be targeted to evaluate Impacts deriving from the State indicators provided by IAM. Evaluation procedures may be implemented by focusing on the link between S and I and between I and R by adapting concepts and methods derived from MCA literature, Multi-Attribute methods in particular [Hwang and Yoon, 1981]. Within this disciplinary context a preliminary phase of Problem Structuring is targeted to the identification of the criteria to be considered for choosing among previously defined options. These factors are expressed as indicators deriving from output variables of IAMs or monitoring activities. The step between the quantification of State variables and the identification of Impact evaluation indices can be conceptualised according to MCA theory as the conversion of the Analysis Matrix into an Evaluation Matrix (EM), which expresses the estimated impacts.

Having identified the impacts as they vary under the effects of alternative response options, the decision maker has to apply a decision rule to aggregate the values stored in the EM to identify the preferred option, filling therefore the gap between I and R. In the simplest case, the rule can be expressed by the weighted sum of values stored in the columns of the EM. Various iterations are possible and needed at this step to refine the weights, or apply alternative decision rules by considering the results of the sensitivity analysis to select a robust response. Parallel procedures are also possible in multi-stakeholders group decision making.

Assessment methods: a dynamic and integrated DPSIR-DSS tool

Communication about how decisions are reached is greatly facilitated using a DSS in which effects of alternative options can be explained and their impacts assessed in a form, which can be comprehended by the non-expert. Similarly, a DSS is ideally suited to answering questions arising from policy changes on water resources by providing the understanding of the processes involved, evaluating the consequences and delivering advice.

In accordance with the WFD, the DSS developed by the MULINO project integrates hydrological and socio-economic approaches in order to assist water authorities in the management of water resources. A key issue from a methodological viewpoint is to guarantee the possibility of feeding decision matrices with social, economic and environmental criteria, to allow decisions to be taken in a perspective of SD. This aspect was tackled by allowing D and P indicators to be considered as decision factors within the AM.

4. CONCLUSIONS

There is a clear need for methodologies and tools to put IWRM principles into practice, in an application context in which decisions and choices are assessed in terms of their sustainability not only over the long term but also with regards to their day-to-day contribution to the perspective of sustainable development.

The need mentioned above may also be described in terms of the implementation of an integrated methodological framework allowing decision makers to choose first and then to monitor the process induced by their decisions.

Various methods and tools, such as modelling, environmental impact assessment and decision support, have shown to provide rational insight in the system's behaviour and the problems addressed. However, integration remains a difficult issue.

The 4-step process described above may contribute to provide methodological support to cope with the problem mentioned above, focussing in particular on:

- the complexity of decision context typical of IWRM;
- the large amounts of multi-sectoral and multidisciplinary information;
- the need to efficient communication between the scientific and the policy sector and between decision makers and the involved stakeholders.

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4.5 EVALUATION OF ALTERNATIVE OPTIONS FOR THE IRRIGATION AQUEDUCT OF THE CAVALLINO PENINSULA USING THE MULINO APPROACH

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Evaluation of alternative options for the irrigation aqueduct of the Cavallino Peninsula using the MULINO approach

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Abstract

In the present article we analyse the problem and the effects of changes in irrigation technology that affect a farmer community in the Cavallino Peninsula in the northeast of Italy. The obligation of closing and sealing the wells, which are currently used in the area for irrigation purposes is due to a national law aimed at preserving the groundwater resources and preventing subsidence phenomena in the Venice area. The enforcement of this law implies that the regional administration is obliged to provide farmers with a sufficient water supply for their agricultural activity. The methodology developed within the MULINO Project was used in this analysis, to test the potentials of a decision support system tool (mDSS) developed by the project. Firstly, the decision context was analysed and, as result, the problem was subdivided in two more specific sub problems: one related with water abstraction and the other related with water distribution. In order to build the decisional model, the opinions of experts and the preferences of the stakeholders were taken into account in different phases of the process. The results allowed the competent administration to identify the stakeholders' main concerns about the development of a new irrigation system and to develop strategies to cope with them. The quality of the water supplied and the economic effects of the change in the irrigation system were the main issues dealt with in this process. The application of the MULINO approach and DSS tool added efficiency and transparency to the decision making process, by allowing the elicitation of opinions and preferences of all the actors involved in the process, and demonstrating that, notwithstanding the different viewpoints and interests, a general consensus could be reaches on a single management option.

Key-words: irrigation, decision support system, multicriteria analysis, public participation.

1. Introduction

Like environmental planning in general, Integrated Water Resources Management (IWRM) is usually characterised by the involvement of numerous decision-makers operating at different levels and of a large number of stakeholders with conflicting preferences and different value judgments (Lahdelma et al., 2000). This makes the development of policy implementation strategies and decision-making in the context of IWRM a very complex issue, since it also requires a broader integration with other sectors such as environment, energy, industry, agriculture and tourism.

Adequate methodologies and tools are therefore necessary in order to measure how a specific policy meets the objectives of the various actors, to identify and understand the possible conflicts that may arise between these actors and, finally, to design possible paths and courses of action to arrive at a sustainable solution. Science and research are called upon to play a stronger and more policy relevant role to find adequate methodologies and tools (ICSU, 2002).

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The European Water Framework Directive (WFD) (EC, 2000) specifically addresses public information and consultation in Article 14. The Member States have to involve the public in the implementation of the Directive by publishing specific information relevant to the River Basin Plans and by being open to the public's comments about the planning process. Member States should also encourage the active involvement of all the interested parties, which requires more than the publication of information, and this is a novelty for some European countries, including Italy.

EU Member States with little experience in public participation, may find the implementation of the WFD principles very challenging. Establishing new lines of communication and the facilities for collecting and recording public opinions may be costly, and such procedures may be incompatible with current planning approaches. Moreover, there may be resistance to what may seem like a step towards a redistribution of power that threatens the freedom of individuals or organisations to make decisions in a non-transparent way.

Clear roles played by the various actors are a prerequisite for an effective participatory process. The decision maker is situated in the centre of the decision-making process and has the institutional power and responsibility to select and implement a solution for a specific problem. Stakeholders are all those that may influence or will be influenced by the consequences of the solution adopted and implemented by the decision maker. The analyst, who is the person/group that helps and guides the decision maker to analyse and represent the stakeholders' preference structures and those of the other interested groups, is also often present. This latter role is typically played by scientists in applied research.

In order to facilitate the active involvement of all the stakeholders in water decision problems there is a challenge to be faced: the integration of scientific knowledge and public participation. This is not an easy task.

Indeed, once the crucial importance of public participation in the decision-making process in IWRM has been recognised, the following step must be to clarify how public participation, decision-making and scientific knowledge can be integrated. For this integration, all the meaningful information has to be collected, structured and presented in an understandable way to help decision makers integrate all the actors involved in the decision-making process and all the scientific knowledge available. Decision Support Systems (DSSs) are the tools the scientific literature proposes to cope with such problems in the management decision processes. Several DSSs have been developed in recent years to satisfy this need, for various kinds of water resource planning and management such as prevention of water shortages (drought), surpluses (floods) and water impairment (pollution). Examples of such DSS tools are WATERWARE (Jamieson and Fedra, 1996), AQUATOOL (Andreu et al., 1996), NELUP (O'Callaghan, 1995), FLOODSS (Catelli et al., 1998), DSSIPM (da Silva et al., 2001), STEELGDSS (Ostrowski, 1997).

Another recently released DSS is mDSS, developed by the project MULINO (MULti-sectoral, INtegrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale), funded under the Fifth Framework Programme of the European Union[1]. The mDSS tool has been developed with the specific aim to assist water authorities improve the quality of decision-making and achieve a truly integrated approach envisaging socio-economic and environmental modelling techniques and multi-criteria decision methods, with specific reference to the requirements of the EU Water Framework Directive.

This paper reports the results of the application of the MULINO methodology and DSS tool to the "Cavallino" case study (northeast Italy), one of the test sites chosen by the project to support the development and testing of the approach proposed.

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2. Materials and methods

2.1 The case study

Until now, the water used to irrigate the market gardens of the Cavallino peninsula has been extracted from private wells. This system based on groundwater abstraction must be abandoned as a result of an Italian national law (DL 29/3/1995 n. 96) that prescribes the sealing of all the wells in order to protect groundwater resources and to avoid the subsidence problems that affect the Venice area. According to the cited law, the "Basso Piave" Irrigation and Reclamation Board (BPB) was given the responsibility to design a new public irrigation system, drawing water from the Sile River and distributing it to the farms through a pressurised network.

The process of implementation of the legislative prescription has been slowed down by political debates and social conflicts with farmers' associations opposing the change of current systems. Although the water from the river was shown to be of good quality, farmers (whose main activity is horticulture) were distrustful and asked for further investments in water treatment plants. This opposition was seen, at least by some of the interested parties, as a strategy for stopping, or at least delaying the implementation of the legislative prescription.

Given the complexity of the local situation, the Land Reclamation Board decided to participate in the activities of the MULINO Project and to contribute by including the Cavallino Aqueduct in the list of the project's case studies, in which a new decision support system was to be developed and tested in diverse decision processes in Europe. In the present case the mDSS tool was used to assess the aqueduct project and to evaluate whether additional water treatment plants were or were not a good further solution.

Cavallino is an elongated and thin peninsula that stretches between the Lagoon of Venice (Italy) to the North and the Adriatic Sea to the South (see Figure 1). The landscape is flat and it is made of 2500 ha of reclaimed land (fossil coastal dunes into agricultural land), half of them cultivated. The Cavallino area is part of the wider drainage basin that flows into the lagoon. The soil is sandy, mainly cultivated with horticultural crops, maize and soybean. The wells used for the water abstraction are deep. The water used for irrigation is located in a series of sandy aquifers at depths varying between 80 and 200 m below the mean sea level.

Due to the complexity of the problem analysed, the decisions were formalised and structured in two separate steps: the first one related to the choice of water abstraction and distribution systems and the second related to the possible treatment of the irrigation water, in order to cope with possible qualitative problems.

The first step was formalised according to the Environmental Impact Assessment (EIA) dossier required by the regional administration as part of the project documentation and pre-

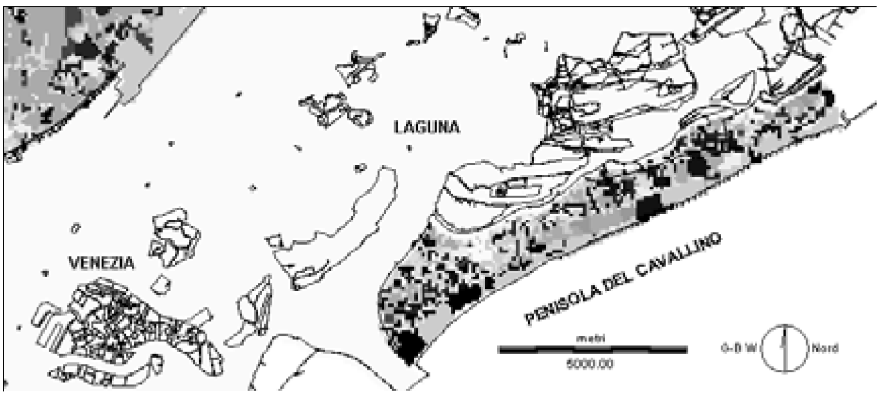

Figure 1. The study area.

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viously drafted by the BPB. The EIA dossier provided information for the definition of the alternative options and the evaluation criteria to be considered for the first step, to be formalised in mDSS, as described in Section 3, in order to provide a further contribution to the analysis and communication of the problem with the interested parties.

Considering that three possible alternatives were available for water abstraction and three for distribution, the result is a theoretical combination of nine alternative options. But, following the indications of the EIA and the interviews with the project designer, only six options could be considered as technically efficient in the paretian sense (see Table 1). For example in order to utilise the Existing branch point (Option 3 concerning abstraction), there is no other possibility than to use a PVC pipe network (option B concerning distribution), because in this option the network must be lain beneath the Venetian Lagoon. Only the combined option 3B was therefore considered in the multi-criteria analysis.

Concerning the criteria to be considered for the ranking of the alternative options in step 1, the EIA dossier also provided the quantification of the performances of the various options, previously acquired by the BPB by interviewing experts, who provided judgments in a scale ranging between -3 for the worst judgement, and +3, for the best judgement.

While the first step was already conducted by the BPB, the definition of the second decisional step was elaborated within the research project and adopted the methods proposed by the MULINO approach, to innovate the usual approach to decision making by emphasising the involvement of the interested actors, through the implementation of participatory processes. Two main activities were put into action to facilitate the involvement of the interested parties: i) a farm survey conducted with a questionnaire (Q1) aimed at investigating the current agricultural systems of the Cavallino Peninsula and the farmers' perception of the project in question (Dridani, 2002); and ii) the stakeholder analysis conducted with another questionnaire (Q2) compiled by means of interviews with a more diversified group of actors, including, besides farmers, representatives of institutions and associations at various levels municipal to regional).

Table 1. The Options – Cavallino.

Option	Abstraction location	Distribution system
1A	Mouth of Sile river	Cement pipe network
1B	Mouth of Sile river	PVC pipe network
2A	Existing pumping station	Cement pipe network
2B	Existing pumping station	PVC pipe network
2C	Existing pumping station	Existing open canal
3B	Existing branch point	PVC pipe network

As shown by the outcomes of Q1, farmers quite often oppose the re-organisation plan for two main reasons: concerns about the availability of water and concerns about its quality. Regarding the first problem, technical agronomic investigations demonstrated that the vast majority of farms will maintain or increase the current volumes of available irrigation water, but with a restriction: differently from the current situation (water available on demand from the private wells) farmers would be obliged to reorganise irrigation with turns of a few hours per day.

Possible limitations deriving from the turns have a rather simple technical solution in building small farm reservoirs, that can be managed with the pumps currently used for the wells. The water quality issue, instead, appeared to be more complex and was therefore deeply investigated in the second step of the decisional process. The analysis of the possible technical solutions in terms of different types of purification systems, allowed the identification of four possible responses to the problem:

- NONDEP: no treatment;
- DEPCEN: centralised treatment plant;
- DEPAZI: farm treatment systems;
- DEPSET: decentralised purification system based on real time monitoring of water quality.

2.2 The MULINO approach for the analysis of alternative irrigation systems

The typical application context for the MULINO methodology and the mDSS software is defined in terms of a decision in the field of sustainable natural resources management and in particular in the IWRM field. The methodology is inspired by the principles of the WFD and has been designed with water authorities as the target users, and its application foresees the involvement of decision makers, experts and

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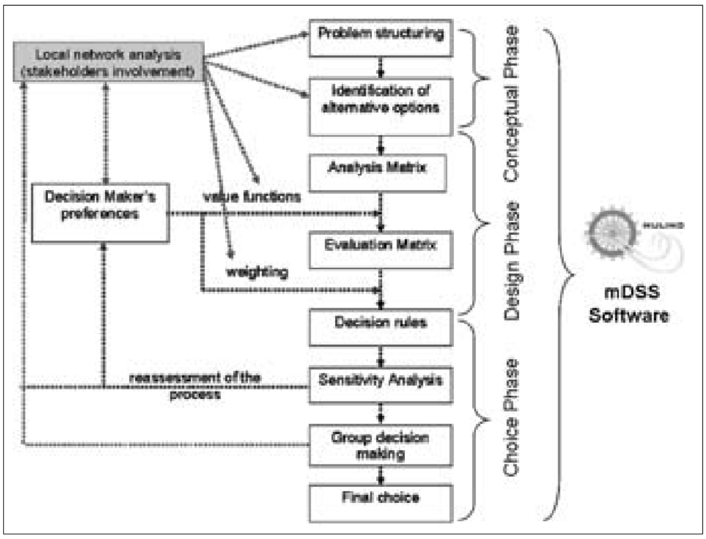

Figure 2. Flowchart of the MULINO methodology.

stakeholders. According to the requirements of the WFD, the approach developed by the project specifically targets the support of the competent authority in managing the planning or decision processes with the active involvement of interested stakeholders (Article 14 of the WFD).

The MULINO methodology leads the user (i.e. the decision maker, DM) through a process that begins with describing and structuring a water management problem, information sharing among selected stakeholders, and finishes with identifying a final choice between possible alternative solutions to the problem (see flow chart in Figure 2).

The involvement of stakeholders begins with the analysis of social networks that serves to disclose the existing relationships between the various actors (including the decision makers) involved in water uses and management within the area interested by the decision to be taken (e.g. a new project or plan). Very importantly, the Social Network Analysis (SNA) as implemented in the MULINO approach, gives the opportunity to identify efficient means for considering the different opinions in the decision process (e.g. the weighting of decision criteria, as described below) and, later on, for implementing them in the decision to be taken.

According to the MULINO methodology, the main stakeholders are initially selected by the competent administration, in this case the BPB, and they may in turn suggest others to be involved (the so-called snow-ball technique). The collection of information about the local network is based upon questionnaires (Q2) compiled by interviewing the selected stakeholders. The questionnaires, designed by the sociologists involved in the project (see Rodrigues et al., 2006, for more details) analyse the local social networks, the relations between actors, in terms of intensity and purpose, and between the stakeholders in the study area. The questionnaires are also aimed at investigating the stakeholders' knowledge about the identified problems, their ideas about existing alternative options, and the criteria to be considered in the choice – as well as their weights.

The data collected in Q2 allow to build a sociomatrix, i.e. a matrix depicting the intensity of social relations within local networks, grouped in six classes ranging from 0 (no relationship existing) and 4 (very frequent – almost daily – contacts). The sociomatrix and other information about social networks were analysed by means of the AGNA (Applied Graph & Network Analysis) software, which provides the following capabilities:

- visual representation of the local network, that also allows clustering various interest groups existing in the network;
- computation of various parameters that characterise the network, such as:
- distances between members of the network (Network diameter, eccentricity, the geodesic matrix, shortest path between individuals);
- sociometric parameters such as nodal degree, density and cohesion of the network, emission, reception and determination degrees, and sociometric status of each individual of the network.

Having analysed the local networks, the MULINO approach envisages the use of mDSS as a means for managing and communicating the whole decision process, culminating with the identification of the preferred choice within a finite set of options, through the implementation of Multi-Attribute Analysis (MAA) methods. According to Simon (1960), mDSS guides the user through three decision phases: "Intelligence, or Conceptual phase", "Design phase" and "Choice phase".

In a typical application, the first step is to identify the study area. Once this has been done, its socio-economic and environmental characteristics are described according to the DPSIR conceptual framework (Driving forces, Pressures, State, Impact and Response) (EEA, 1999). Causal relationships and dynamic interactions within the area are conceptualised in a procedure through which the user is asked to construct DPS "chains" in order to identify the main cause-effect relationships between human activities, described by D and P indicators, and the state, or change of state, of water resources (S indicators). This first phase is termed "Conceptual Phase". The MULINO methodology introduces a local network study to be completed through a series of interviews with selected stakeholders, and the application of modelling tools to analyse the dynamic aspects of the water cycle. The decision maker can thus structure the problem in collaboration with stakeholders, through a questionnaire targeted to the decisional problem in question. The socio-economic and environmental information is stored in appropriate catalogues and organised according to the DPSIR approach in various formats allowing the user to deal with spatial and temporal data series.

The user is then ready to enter the "Design Phase" where he/she describes the alternative options, selects the decisional criteria taking into account the results of the local network analysis, and the results of data coming from surveys, census, monitoring and modelling are stored in the Analysis Matrix (AM). The AM is structured with options in the columns and decisional criteria in the rows. Criteria are quantified by means of the indicators selected within the DPSIR conceptual framework built in the Conceptual phase.

The evaluation, normalisation and weighting of the multidimensional data stored in the AM take the decision maker to the "Choice Phase" in which the Evaluation Matrix (EM) is built, and one or more decision rules are applied to identify the "best" option. Local network questionnaires are designed to support public participation by collecting structured information about stakeholders' preferences that relate to the decision problem. These preferences can be combined in the mDSS's group decision-making routine.

In this final phase, the mDSS software allows the user to analyse how the variables influence the selection of the preferred option through the sensitivity analysis and, finally, a "sustainability chart" is provided to assess the balancing of social, economic and environmental performances of the various options (more details about MULINO and mDSS can be found in the MULINO Project, 2004).

3. Results

3.1 Analysis of the altenative abstraction and distribution systems

As previously stated, the results of the EIA previously carried out by the BPB were elaborated to be implemented in the mDSS, in order to allow for more efficient data processing and communication with the interested parties. The judgements expressed by the experts regarding the performances of the 6 possible options for water abstraction and distribution (originally scaled between -3 and +3, as reported in Table 2) were normalised to fall between 0 and +1 using simple benefit type value functions, to provide the values for the mDSS Evaluation Matrix. The decision maker preferences were further investigated by eliciting the weights to be assigned to each decision criterion using a hierar-

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Table 2. Analysis matrix of Step 1: abstraction and distribution options.

	OPTIONS					
CRITERIA	1A	1B	2A	2B	2C	3B
Quality of abstracted water	1	1	3	3	3	3
Quality of transported water	3	3	3	3	-1	3
Impact with the river ecosystem	-3	-3	0	0	0	0
Punctual landscape impact	-1	-1	0	0	0	-2
Lineal landscape impact	3	2	3	2	-1	2
Socio-econ. impact of abstraction system	3	3	2	2	2	1
Socio-econ. impact of distribution system	2	-1	2	-1	3	-1
Losses in the network-efficiency	3	2	3	2	-1	2
Material and installation costs	3	2	3	2	-1	2

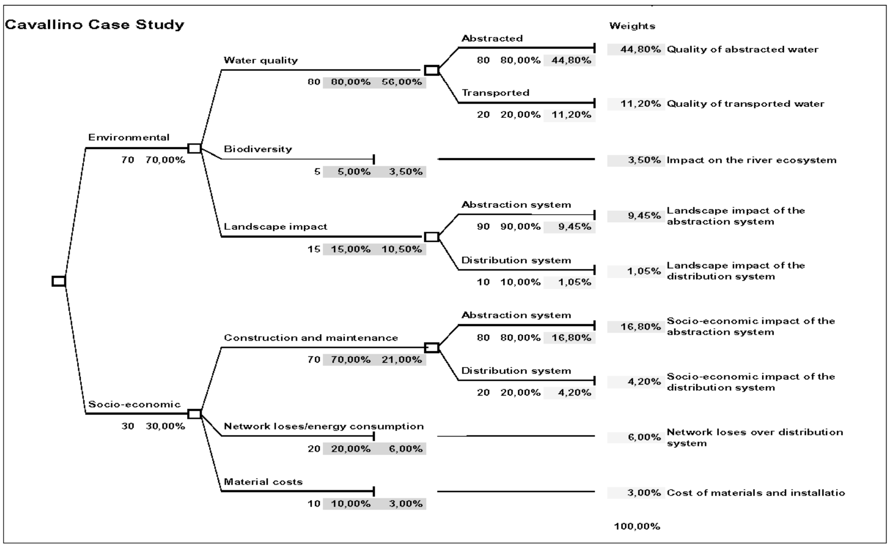


Figure 3. Results of the hierarchical weighting procedure (Step 1).

chical approach. Firstly, the DM was asked to assess the weights of two macro-criteria (environment and socio-economics). After that, for each macro-criterion, the DM was asked about the relative importance of the criteria within the two macro-criteria, and so on for the three hierarchical levels. The final weights were calculated by multiplying the criterion weight by the relative weights until the last level of criteria (Figure 3)[2].

[2] This top-down weighting procedure was more intuitive for the DM, when several criteria should be considered, because it appeared to be very difficult to express the set of weights to a very long list of criteria at the same time.

Having defined the contents of the EM and the criterion weights, decision rules were used to compare the different options. The evaluation using Simple Additive Weighting shows that option 2A should be preferred, i.e. the utilisation of an existing pumping station along the Sile River to divert water to the Cavallino Penisula by means of a cement pipe. Even if it is difficult to say that the differences are determinant, one can certainly conclude that option 2 (the water abstraction place) is dominant. This would suggest further analysis to obtain more precise data about the distribution system starting from the abstraction point 2. The evaluation using

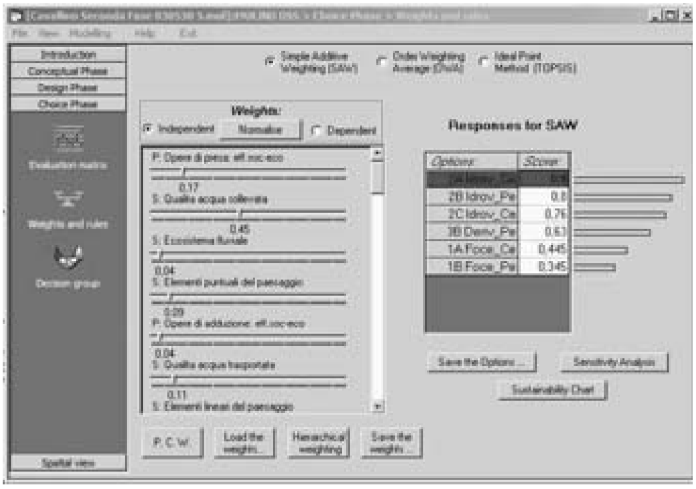


Figure 4. Ranking of alternative abstraction and distribution systems (Step 1): results of the Simple Additive Weighting.

other decision rules gave the same results as the Simple Additive Weighting, thus supporting the idea about the robustness of the ranking. Figure 4 shows the ranking of the options through the interface of mDSS.

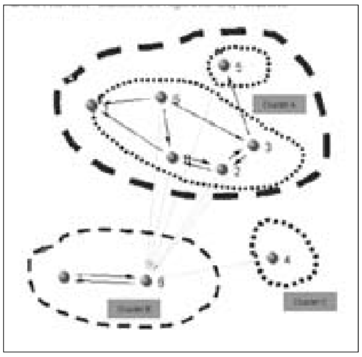
3.2 Selection of most suitable option for water treatment

Amongst the efforts for establishing fruitful communication and collaboration with stakeholders of the Cavallino Peninsula, the abovementioned farm survey was preliminarily carried out to define Step 2 of the decision process. The main results about the part of the questionnaire (Q1) targeted to the farmers' perception of the planned aqueduct show that 98% of them were informed about the project, mainly through their associations that informed them.Athey were informed also about the expected long-term environmental impacts of the current irrigation system, that motivated the reorganisation project. The majority of the farmers (71%) perceived problems in their sector mainly related with soil availability, drainage and water quality, but the main issues expected from the project are related with water quality, water availability and economic impacts in their activities. Having identified the water quality issue as the main focus of the following step of the study, it appeared clear that the main institutions involved in water management were to be involved in the participatory process, through the Social Network Analysis (SNA). The BPB was included in the interviews to allow for acquiring information about the existing networking and, in case, for identifying possible strategies for improving relationships and communication with the various stakeholders.

The analysis of the sociomatrix produced with the questionnaires and the elaboration provided by the AGNA software allowed for identifying the intensity of communication between stakeholders and for clustering of stakeholders after analysing the network for frequent (3) and very frequent (4) interactions between individuals.

Three important clusters of entities (individuals or groups/institutions) with intensive communication ties can be identified from the image:

- Cluster A – Groups or individuals involved in the use of water for agricultural purposes:
  - Farmers and agricultural associations (entities 2, 3, 6 and 8 in figure 5);
  - Land Reclamation Board (also end user);
  - Municipal administration of Cavallino – Treporti.
- Cluster B – Environmental decision makers at the regional level:



1	**Consorzio di Bonifica (Decision maker)**
2	**Farmer 1**
3	**Farmer 2**
4	**Civil Engineers Regional Office**
5	**Municipal Administration Cavallino-Treporti**
6	**Confederazione Italiana Agricoltori**
7	**Veneto Region - Dept. Special Law for Venice Lagoon**
8	**Coldiretti**
9	**Veneto Environmental Protection Agency**

Figure 5. Intensity of the local network.

Table 3. Evaluation Matrix. Step 2.

	OPTIONS			
CRITERIA	NONDEP	DEPCEN	DEPAZI	DEPSET
Quality of water	0.04	0.15	0.51	0.30
Investment costs	0.62	0.06	0.19	0.14
Maintenance costs	0.64	0.05	0.11	0.21
Ease to manage	0.69	0.16	0.06	0.10

  – Veneto Region – Dept. for Special Law for the Venice Lagoon;
  – Veneto Environmental Protection Agency.
- Cluster C – Regional Civil Engineers Department[3].

Regarding the Density of the network, which represents the actual number of connections reported to the total – and theoretic – number of available connections, the Cavallino network (0.75 – in the value range 0, 1) was observed to be high, thus showing that most of the available connections between individuals are practically used.

Regarding the Cohesion parameter (an index showing the degree of reciprocity of the connections, i.e. the actual number of reciprocal connections divided by the total number of possible reciprocal connections), the Cavallino network once again showed a high value, with a cohesion index of 0.61 (higher than 0.5).

[3] This can be considered as a cluster by itself, as it represents the regional authority that delivers technical permits for water abstraction from wells, being thus in a not frequent contact with none of the other individuals of the Cavallino local network.

More information about the Sociometric Status (i.e. the intensity of communication of an individual with the other partners with whom he/she is in direct contact) and the identification of shortest communication paths from end user to stakeholders were calculated for the use of BPB, and are not reported here for brevity. Worth to note is the fact that, given the limited size of the area, the social actors involved in the network showed to have good opportunities to communicate directly, without intermediaries.

Having defined the structure of the local networks, the analysis matrix was obtained from the BPB experts by using a pairwise comparison for each criterion, based on their knowledge and experience. The value functions were constructed using the benefit type shape, from which the evaluation matrix reported in Table 3 was obtained.

Stakeholders being grouped according to the clusters described above, the results of Q2 were processed to derive the values of weights expressing the preferences per social group. Thus, the result of each weight of criteria is the arithmetic average of the weights expressed by each

Table 4. Aggregated weights of criteria by cluster.

	CLUSTERS				
	A	B		C	
	WEIGHTS				
CRITERIA	Average	Average	S.D.	Average value	S.D.
Water quality	0.00%	26.78%	0.07127	39.76%	0.144834
Ease to manage	29.17%	24.31%	0.086642	27.51%	0.206351
Maintenance cost	29.17%	19.86%	0.088039	12.23%	0.118088
Cost of investment	29.17%	13.34%	0.004192	12.23%	0.118088

of the interviewees belonging to the same cluster. Table 4 presents the averages and standard deviations of the weights expressed by the clusters.

As pointed out by Q1, water quality is a production factor of primary importance for the horticultural systems located in the Cavallino Peninsula. It thus becomes of uppermost importance for the cluster involved in agriculture (almost 40%). It is also of high importance for environmental regional organisations, that take into account more criteria than the individuals in the agricultural cluster did (the more criteria we have – the lower is the relative weight).

In the case of environmental decision makers, water quality is now seen more like a raw material, as the evaluation of water quality as an environmental criterion was made in the previous step of the analysis. The cluster consisting only of the Civil Engineers Dept. from the Veneto Region pays no attention at all to water quality, as the subject lies outside their responsibilities. They focus mainly on the costs (both investment and maintenance) involved by the project – and consider also the project's manageability more than the other clusters.

Having defined the contents of the AM for the second step of the analysis and the weights of criteria, the last phase of the decision process was the identification of the preferred option for water treatment. Here the results of social network analysis were used to compare the preferences of the three groups of stakeholders representing different points of view about the problem.

Simple Additive Weighting was used for the comparison of the alternatives because it is the simplest and the most comprehensible one for all types of stakeholders. The ranking obtained by the different sets of weights, as shown in Figure 6, was similar, demonstrating that, notwithstanding the different opinions about the problem in question, all the groups concluded that the preferred solution should be to avoid any investment in treatment plants.

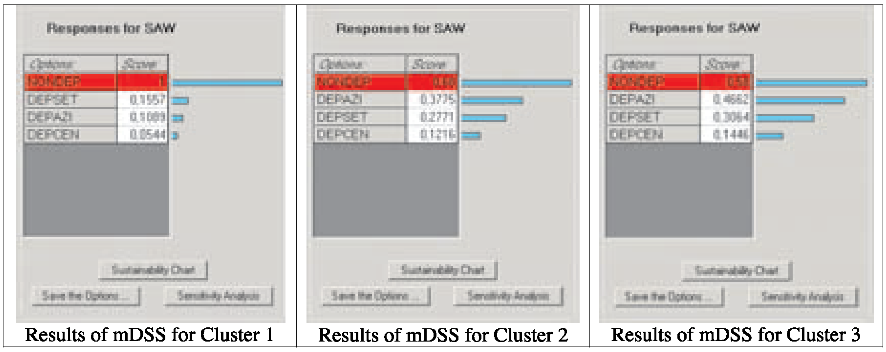


Figure 6. Results of the Simple Additive Weighting according to the preferences of the various social clusters for what concerns water treatment (Step 2).

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4. Concluding remarks

The MULINO approach and, in particular, the combination of SNA and the mDSS tool, showed potentials to formalise and standardise the decision process, thus allowing parallel, but coherent and comparable, decision processes to be carried out by different stakeholders. The mDSS tool was useful for working at the interface between technical and political "bodies" within the administration, and for supporting the political side, by facilitating the introduction of more transparency and efficient communication. It served to implement both the results of the Environmental Impact Assessment and those of the analysis of alternative options for water treatment.

This study demonstrated also the usefulness of the mDSS when confronting the preferences of a range of stakeholders.

On the other hand it appeared clear that the implementation of mDSS requires a trained user, i.e. a motivated user with time available to invest in learning how to use the tool and the description of DPS chains, though providing a useful support for clarifying the decision background and its interpretation by the decision makers, showed to be in some cases subjective or ambiguous.

Public participation was rather unusual in the area, at least as a structured and formalised process. If found a positive attitude for collaboration both within the farmers and among the institutions involved in the process. Unfortunately, difficulties found by the project at higher decisional levels in the implementation of the choices made, which slowed down the realisation of the project, could negatively affect the credibility of participatory approaches in future cases. Efficient communication wit all the involved parties could limit these negative consequences.

Acknowledgements

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4.6 DECISION SUPPORT FOR STRATEGIC WATER MANAGEMENT: MDSS IN THE LARGE DAM CONTEXT

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Decision Support for Strategic Water Management: Mdss in the Large Dam Context

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Abstract: *Based on findings from a review of the effectiveness of large dam projects worldwide, the World Commission on Dams (WCD) has stressed the need for an assessment of alternative options to improve decision-making processes in water resources and energy development. Besides the importance of rights affected and risks caused by the projects, the need to consider equity issues was also emphasized. Multi-criteria analysis (MCA) methods were recommended to support decision-making in a cross-disciplinary context.*

The aim of this paper is to test the potential of the recently developed MULINO methodology and DSS tool (mDSS) in support of the implementation of the WCD recommendations in future dam projects. Superimposing the DPSIR approach (Driving force – Pressure – State – Impact – Response) and multi-criteria analysis methodology, mDSS was applied in a theoretical re-assessment of the decision to undertake the Ceyhan Aslantas Dam Project, which took place in Turkey in the early 1970s. Using the information available from the case study of the WCD, the application of mDSS provides insight into the values prevailing among decision makers, stakeholders and experts in the region with respect to the notion of sustainability. An exploration of the uncertainties associated with the information supporting the planning process, and of their possible effects on decision-making, is also specifically addressed. Applications of sensitivity and sustainability analysis were enlightening with regard to the specification of methodological advancements. Referring to large infrastructure projects, the problem of structuring needs to be revised. Allowing for the identification of descriptive, as well as value-oriented, normative criteria, the analytical potential of the mDSS tool is strengthened with regard to sustainability.

Keywords: *Decision support system, integrated water resources management, multi-criteria analysis, decision-making, dam, DPSIR.*

Introduction

According to the sectoral review of large dams carried out by the World Commission on Dams (WCD, 2000), overall, dams have often not reached their physical targets; they have not recovered their costs and have been less profitable in economic terms than expected. They have also shown a marked tendency towards cost overruns, as well as schedule delays. Project benefits were, in general, only possible at the cost of serious environmental and social, as well as economic, impacts that were borne by communities downstream, by the environment, by the taxpayer and also by the people displaced. This raises the issue of inequity and expediency in undertaking a project.

Although these findings may question the overall effectiveness of the projects, the WCD also recognizes the important contribution made by dams to human development and their considerable benefits for the society. These include balancing the uneven distribution of water in space and time, providing water for consumptive uses and pressure heads for hydropower generation, as well as regulating downstream runoff for flood protection or low flow augmentation (WCD, 2000). Considering the increasing food, water and electricity needs of a growing world population, along with an increase in the standard of living, new water resources and electricity development projects may be necessary, and large dams present one alternative among others.

Based on the core values of equity, sustainability, efficiency, participatory decision-making and accountability, the WCD defined strategies to be followed during planning and project operation in order to avoid the experience of the past: gaining public acceptance; comprehensive options assessment; improving the efficiency as well as the environmental and social performance of existing dams; sustaining rivers and thus the livelihoods of local communities; recognizing entitlements and sharing benefits; ensuring compliance with regulations and agreements; and sharing rivers for peace, development and security.

The resulting need for multi-sectoral and multidisciplinary assessment and decision-making requires the joint implementation of integrated modeling tools with decision support tools as provided in mDSS, the software tool developed by the MULINO Project (Giupponi et al., 2003). MULINO is the acronym for the project entitled "**Mul**ti-sectoral, **in**tegrated and **o**perational decision support system for the sustainable use of water resources at the catchment scale", funded by the European Commission (EVK1-2000-22089) in the period 2001-2003. The MULINO Project developed a methodology that aims to support the implementation of the EU Water Framework Directive (EC, 2000). It provides an integrated framework for sustainable water resources management and decision-making by employing Multi-Criteria Analysis (MCA) methods.

This paper presents the procedure implemented and the results obtained from testing the MULINO methodology and DSS tool in the large dam context, giving special consideration to the notion of sustainability. The application of mDSS has an exploratory character and is built upon a theoretical reproduction of the decision to build the Turkish Ceyhan Aslantas Project in the 1970s. The project aimed to irrigate 97,000 ha of land in the lower Ceyhan basin, generate 500 GWh/y of hydropower and reduce the frequency of floods downstream. The information provided by the WCD case study on this project (Agrin Co. Ltd., 2000) was then used to evaluate the "No-change" option, by projecting the local conditions before the dam was built to the year of project implementation (1985), in comparison with the "Dam-planned" option using the information projected for 1985 in the planning documents of the time.

Additionally, the use of the MULINO approach as a means for investigating the inherently uncertain effects on performance and preference information was explored. To this end, the information available in the WCD case study on actual project turnout was introduced as the "Dam-reality" option to a purely hypothetical comparison. The lack of detailed temporal and spatial information limited the selection of evaluation criteria and impeded the design of alternative options using different technologies to deliver the same uses. Nevertheless, the information available allowed an explorative testing of the cited methodology with the aim of assessing its current potential and identifying further research needs. Due to the described information basis, any judgment about the alternative options compared in this paper, i.e. whether the dam should have been built or not, is outside the scope of the present work.

The Mulino Methodology In Brief

The MULINO methodology was designed to provide a generic approach to a variety of decision problems in the field of water management (see Giupponi et al., 2004 for details).

Following the three consecutive phases of a decision-making process (Simon, 1977), the unifying structure of the mDSS user interface superimposes two theoretical concepts: the DPSIR approach (Driving force - Pressure – State of the environment – Impact – Response) developed by the European Environmental Agency (EEA, 1999) and multi-criteria analysis. Firstly, in the Conceptual Phase, the DPSIR approach allows the user of MULINO to formalize the decision situation on the basis of cause-effect relationships, linking Driving forces, Pressures and the State of the environment (DPS chains).

In the following Design Phase, possible options – i.e. Responses in the terms of the DPSIR framework – are identified, together with the quantitative and qualitative criteria upon which their performance must be evaluated. Indicators quantifying the options' performances on the criteria are determined by applying simulation models and other elaboration procedures, such as analysis of spatial information using GIS tools or the application of analysis methodologies or literature. mDSS provides a generic interface facilitating exchange and integration of spatially and temporally distributed data.

Finally, in the Choice Phase, as the core of the MCA procedure, the natural scales of the multidimensional decision problem, as presented in the Analysis Matrix (AM), are transformed into a one-dimensional 0-1 preference scale in the Evaluation Matrix (EM) using partial value functions. Via the application of decision rules, the partial preferences describing individual criteria are aggregated in a global preference, ranking the options. In addition, the mDSS tool provides capabilities for sensitivity and sustainability analysis and assists in finding compromise solutions supporting stakeholder involvement in group decision-making.

The application of mDSS to strategic planning decisions, as in the case of large dams, evidenced some limitations that required two main conceptual developments to the approach described above (Figure 1). Firstly, societal needs (NEEDS) and external drivers (EX-D) were formally introduced into the process. Large dams are one possible response to the societal needs for water and energy supply. The implementation of large dams then induces cause-effect chains linking human activities to the state of the environment. External drivers are elements of the natural environment that cannot be influenced by the responses, although they are a relevant element of the DPS chains, such as climate change. Secondly, DPSI chains were considered instead of DPS chains. Changes in the state indicators, e.g. water quality, water quantity and river morphology caused by large dams, have serious impacts on the environment and society, resulting in diversified cause-effect chains. The limited number of state indicators requires that the impact indicators represent the relevant cause-effect chains in the analysis matrix. Each Response effect may then be formalized as a distinct chain consisting of DPSI, PSI, SI or I elements, as will be specified in the test of the MULINO approach (conceptual phase).

The Ceyhan Aslantas Project

In the 1960s, expansion of agricultural production in Turkey was required to feed the increasing population, to increase exports and foreign exchange receipts, to create more job opportunities and to improve farmers' standard of living. Five dams on the main Ceyhan River and 12 dams on tributaries were projected in a report by the International Engineering Company Inc. (IECO) in 1966. Aslantas was the first to be built and went into operation in 1984 (hydropower) and in 1985 (irrigation) with a delay of 3 and 4 years,

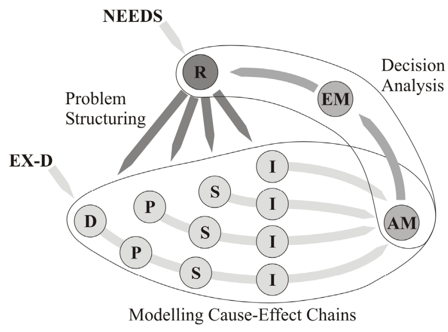


Figure 1. DPSIR scheme

respectively. The following description of the Aslantas Project is based on the WCD case study (Agrin Co. Ltd., 2000).

Rising in mountains of 2200 m in the eastern Mediterranean region of Turkey, the Ceyhan River runs southwest on a river length of 509 km before flowing into the Mediterranean Sea near Adana. The basin covers 2,067,000 ha (1 ha = 10,000 m^2) within the Kahramanmaras, Osmaniye and Adana provinces. An annual precipitation of 400 to 700 mm in the north and 1,000 to 1,200 mm in the south in combination with a high level of evapotranspiration necessitates irrigation for optimum agricultural production. Overall, the Ceyhan catchment holds a potential of up to 590,000 ha of irrigable land.

The 78 m high earth-fill dam has created a reservoir area of 4,900 ha equaling $1{,}150 \cdot 10^6$ m^3 of storage volume to serve irrigation and flood protection, while at the same time creating the water head for hydropower generation. Three 46 MW units on average produced 31 % more than the planned 500 GWh/y. In addition, the Ceyhan River dykes were raised, reinforced and extended on a river length of 59 km. The dam height was designed to save the historical Karatepe site and Haruniye thermal facilities from flooding. The overall investment of US$ 885 million (1989) considerably surpassed the initial estimation of US $ 552 million (1989) during the planning stage. Because the cost recovery of the project is rather poor, the taxpayer is bearing the financial costs.

The resulting irrigated area on either side of the river covered an area of 93,000 ha, or 95 % of the area planned. By 1997, it had dwindled to 84,000 ha due to subsequent industrialization and infrastructure development. The irrigation scheme's overall efficiency of 43 % has fallen well short of the 60 % planned. Owing to the unplanned introduction of second crops, the cropping intensity, calculated as the total area cultivated (considering both rain-fed and irrigated crops) in a full year divided by the irrigation command area, has risen to 10 % more than predicted. Nevertheless, the production value has remained less than predicted, partly due to the significant decrease in cotton cultivation. The demand for farm labor decreased by 7 %, instead of increasing by an expected 144 %, although numerous jobs were created in the agribusiness sector. In order to maximize irrigation benefits and sustainable land resource use, on-farm infrastructure was implemented as planned, with the exception of drainage facilities.

Positive effects on net farm incomes were drastically overestimated, especially for small land holdings. Structural changes and institutional strengthening (e.g. land reform, capacity building, mechanization, farmer training) that were planned but not implemented, diminished the project outcome in terms of improved land distribution and increased farmer incomes. Other socio-economic problems raised by the WCD case study relate to the compensation of 953 resettled families, which was based upon the low values that had been declared for taxation by the farmers. The resettlement of 47 families was concluded only seven years after flooding and was found to be partially inadequate. In general, people lacked support to cope with their new situation. Conflicts between host and resettled communities were not recorded.

Impacts on the environment, as well as regional and national development, were paid little attention when the dam was designed and planned, and hence today are hard to identify. The diversity of terrestrial habitats decreased mainly due to the impoundment of the dam, but also due to human activities. None of the areas lost were considered unique. The wide water table of the reservoir has created new habitats for aquatic life but at the same time has caused native trout and eel populations to disappear and impaired the habitats of invertebrates and microorganisms. The sediment regime of the river has been altered, but neither the impacts of erosion nor sedimentation are considered to be a problem. Moreover, intensive agriculture, urban growth and industrialization increased water pollution, thus impacting the irrigation system. The unforeseen introduction of *oriental sore* to the region has detracted from the success of controlling the increase in *malaria*. Society in general has profited from the electricity generated and the increased agricultural production at local, regional and national levels. Positive regional developments with regard to health and educational services, water and electricity supply, nutrition and the development of all agriculture-related branches of business have been attributed to the dam.

The Test Of The Mulino Approach

Preliminary analysis of the decision context: the Conceptual Phase

The analysis of dam-related cause-effect chains identifies first of all changes in the state of the physical environment. Specifically, changes in water quantity, water quality and river morphology are recorded. These result in direct and indirect impacts on the physical and living environment, such as increased intensity of water use, introduction of new species or loss of habitats. Beyond particular individuals, society as a whole is also affected by these changes of the state of the environment through, for example, resettlement, the necessary adaptation of economic life and regional development. Furthermore, influences on economic developments, i.e. local labor market, crop production, availability of electricity, can be observed. The limited number of state indicators makes them unsuitable for unambiguously characterizing the effects of large dam projects. In the given case, only impact indicators were selected as criteria for MCA methods. They were grouped hierarchically under three macro-criteria, representing the three pillars of sustainability, as listed in Table 1. Full-length DPSI chains are only used to represent activities made possible through the dam, such as irrigation or industrialization. Since such activities influence the same states of the environment and thus impacts as the dam, no extension of the identified Impact indicators is required.

Some of the indicators comprise information from various relevant aspects. For instance, the indicator "riverine habitats" includes influences on wetlands in the reservoir and downstream but also on lagoons and coastal zones. Oxygen concentration, the presence of phytoplankton, performance with regard to quality requirements and influences due to irrigation return flow are summarized as "water quality" indicator. Furthermore, sedimentation and erosion are considered in the catchment, in the reservoir, downstream of the dam and in the river delta. General developments such as health service and educational services, but also water and electricity supply and the overall nutritional situation together with cultural and recreational aspects, are grouped under the "living standard" indicator.

Data from the WCD case study were extracted to provide indicators satisfying the properties that are relevant to MCA methods and, in particular, enabling the use of the simple additive weighting methodology (SAW), as specified by Keeney (1992) and Belton and Stewart (2002). Above all, the individual criteria should be relevant, unambiguous, operational with reasonable effort, and their performance should be measurable to some extent. In general, proof of their fulfillment is difficult to determine. For example, the complexity of the large dam context makes it impossible to ensure that the performance of the criteria selected is only influenced by the choice of alternatives that are analyzed in the decision context (i.e. controllability). External influences can never be eliminated completely, i.e. external societal developments that are independent of the dam project might nevertheless influence the outcome of the project. In order to apply simple additive weighting the criteria should furthermore be preferentially independent, i.e. preferences between two criteria should be independent of the level of performance of all other criteria, measurements should use an interval scale and weights should be understood as scaling constants. Being different from structural or statistical independence, preferential independence in complex contexts is difficult to prove due to the lack of methodological approaches. In spite of the broadness of the criteria, an attempt has been made to define criteria and preferences accordingly. The property of interval scale measurement was found to be a limitation especially for qualitative criteria.

In real-world cases, it is recommended that the criteria, goals and objectives (preferences) being considered should be specified by the groups of decision makers concerned, the people affected by the project or relevant non-governmental organizations (NGOs). This approach was obviously impossible. The present study has an explorative, theoretical and *a posteriori*

Economic macro-criterion

Criterion	[Unit]	No-dam	Planned	Reality	Value Funct.
1 Total crop value (1984)	*% of TL*	100	288	196	MAX./LOCAL
2 Jobs in agribusiness	*No. jobs*	9,800	22,411	14,281	Max./local
3 Construction costs (1998)	*10^6 US $*	0	552	885	Min./local
4 Electricity generation	*GWh/y*	0	500	653	Max./local
5 Crop production (t)	*%*	100	183	269	Max./local

Environmental macro-criterion

Criterion	[Unit]	No-dam	Planned	Reality	Value Funct.
6 Terrestrial habitats	*q*	0.00	-1.00	-2.00	Max./global
7 Riverine habitats	*q*	0.00	-1.00	-2.00	Max./global
8 Intensity of water use	*% run-off*	2.30	21.60	23.10	Min./global
9 Water quality	*q*	0.00	0.00	-0.75	Max./global
10 Sediment regime	*q*	-0.25	-0.50	-1.00	Max./global

Social macro-criterion

Criterion	[Unit]	No-dam	Planned	Reality	Value Funct.
11 Net farm income (1984)	*%*	100.0	314.0	108.0	Max./local
12 No. of people resettled	*% loc. pop.*	0.0	2.9	2.9	Min./local
13 Compensation quality	*%*	100.0	75.0	61.0	Max./global
14 New diseases	*q*	0.0	0.0	-2.0	Max./global
15 Living standard	*q*	0.0	+1.0	+1.7	Max./global

from '84/'85
average or either of '96-'98
data from '72/'73
average for '84-'98

q: qualitative
TL: Turkish Lira
(19xx): base year of value conversions

Table 1. Analysis Matrix

character.

Assessment of alternative dam options: the Design Phase

In the Design Phase, possible Responses, or alternative "options" to the pressing societal needs for water, energy and food adopted by mDSS, are specified. The corresponding performances of the indicators selected in the previous phase are determined for all options, thus compiling an analysis matrix (criteria x alternative design option).

Among the various limits of the discussed application, it should be mentioned that the projection of conditions to the year 1985 prior to building the dam did not consider any general development that may have taken place due to external influences. Hence, the "No-change" option has to be considered more pessimistic than it would have been in reality, while the "Dam-planned" option used the most consistent data set with regard to the reference point in time. The "Dam-reality" option used information about the actual project outcome, observed in the period from implementation in 1985 until 1998. The options and indicators deployed in mDSS are depicted together with the corresponding data in the analysis matrix in Table 1. The WCD case study provided cost and benefit values in US dollars that were converted from current figures to real figures for the base year 1985 (Agrin Co. Ltd., 2000). The Aslantas Dam is part of a cascade of dams on the Ceyhan River. The present analysis is limited to the information provided in the WCD case study, which lacks detailed information on resulting cumulative effects.

Where quantitative information was not available to measure the indicators, qualitative scales were developed. For the environmental indicators this scale ranged from -3 to +3, representing *little*, *some* or *strong* changes, for the better or the worse, as compared to the pre-dam state. The same scale was used to describe the sediment regime, though in this case it represented the intensity of sedimentation and erosion for the option being examined. Within the social criteria, a scale from -2 to +2 was used, distinguishing only between an *increase* or *decrease* and a *considerable increase* or *decrease* as compared to the pre-dam state. The overall score of a qualitative indicator, conveying the combined information on several aspects, was obtained by determining their average value.

Selection of the preferred Response: the Choice Phase

With regard to large dams or other large infrastructure projects, the basic question is whether the supposed physical and economic benefits of the project are worth the associated negative environmental and societal impacts, as well as the associated costs. Furthermore, it is of interest whether those that bear the costs also share the benefits (Nichols et al., 2000). In practice, the aim is to identify the more sustainable response to societal needs. Out of various alternatives, this search can bring forward the idea of constructing a dam.

In the Choice Phase, the values for each indicator in relation to the considered option are compared not only to the goals and objectives of the specific case but to those of society as well. The analysis matrix is transformed into the evaluation matrix using partial value functions to express each option's performance as value scores on a 0-1 range (intra-criterion information). Wherever possible, global (absolute) scales were established, i.e. 0 and 1 values were assigned by referring to a wider set of possibilities, such as the ideal and the worst conceivable performance of a criterion. In all other cases, local (relative) scales assigned 1 to the option performing best and 0 to the option performing worst on a particular criterion.

To ensure flexible adoption in the reproduction of the decision to build the Aslantas Dam, as well as in the hypothetical comparison analyzing the effect of the uncertainty of information, the scales and subsequently the weights were determined considering all three options defined. Both global and local scales were used in the model (see Table 1) depending on the availability of data and existing values of reference. According to Belton and Stewart (2002), there is no difference in the overall performance obtained, as long as the weights

	Criteria	Relative weights A	B	C	Cumulative weights D	E
QU EC	**Economic benefits**					
ALI ON	Agricult. production value	1.00[1]	0.63[2]		0.25	0.03
	Jobs in agribusiness	0.68			0.17	0.02
TY OM	**Monetary costs**					
	Construction costs		1.00	0.40[2]	0.40	0.05
OF Y	**Material benefits**					
LIF	Electricity generation	0.64[2]			0.33	0.04
	Crop production	1.00	1.28		0.51	0.07
E EN	**Habitat status**					
VIR	Terrestrial habitats	1.00[3]			1.04	0.13
	Riverine habitats	1.00	2.00[4]		1.04	0.13
ON	**River status**					
ME	Intensity of water use	1.00[4]	1.00	0.52	0.52	0.07
	Water quality	2.00			1.04	0.13
NT	Sediment regime	2.00			1.04	0.13
SOC	**Individual benefits**					
IET	Net farm income		0.15		0.15	0.02
	Severity of resettlement					
Y	% of local people resettled	1.00[5]	0.10[6]		0.10	0.01
	Quality of compensation	1.00			0.10	0.01
	Regional development					
	Introduct. of new diseases	0.17[7]			0.17	0.02
	Increase in living standard	1.00	1.00	1.00	1.00	0.13
	SUM				**7.86**	**1.000**

[1]128 % increase in jobs (planned) = 128 % increase in production value

[2]range of planned increase valued 1:1
[3]global scales valued 1:1
[4]water use scale values half of the other(s)
[5]global scale = local scale
[6]max. increase of public benefits (0 to 2) =2 * sum of the individual benefits/disadvantages
[7]criteria valued according to aspects considered (1:6)

Table 2. Hierarchical decision tree and swing weights

are properly adjusted to the scales.

To simplify the analysis, and due to the impossibility of analyzing decision makers' preferences, the value functions used in the study were linear and monotonic, as indicated in Table 1, either increasing (max.) or decreasing (min.) the value assigned against the natural scale. The authors are aware that this simplified assumption contributes to the uncertainty of the overall results (Belton and Stewart, 2002). For all criteria the scale and type of value function are listed in the last column of Table 1.

For instance, the intensity of water use was valued on a global scale according to the definition of water stress laid down by UNESCO (1997). Using less than 10 % of the renewable water resources in a catchment is defined as *low water stress*, whereas using more than 40 % of the renewable resources is considered *high water stress*. To obtain the maximum possible quality of resettlement, all people resettled needed to be compensated with the proper amount of money in due time. In addition, long-term guidance was needed to support them in adapting to the new living conditions. For all other criteria, where a global scale was defined, the scale's minimum and maximum values were used (-3/+3 or -2/+2). The scales describe the impact of the options on the respective criteria or, in the case of the sedimentation regime, its occurrence.

Following the criteria-wise scoring of each option's performance, weights representing inter-criterion information are assigned. To determine the relative importance of each criterion, a bottom-up swing weight approach was implemented, as described by Belton and Stewart (2002). The term *swing* refers to the range from *worst* to *best* value on each criterion's relevant scale, i.e. the value range represented by the value scores 0 to 1. Hence, by comparing the swings of different criteria, a decision maker assigns weights according to how much he/she prefers one criterion to "swing" (be improved) from worst to best performance instead of another criterion.

This understanding implies that a change in scales requires a change in weights. In the hierarchical decision tree developed for the Ceyhan Aslantas Project, the swings were first compared within the criteria families at the bottom level of the tree (column A of Table 2). One assumes, for example, that the planned increases in electricity generation and in crop production, i.e. the difference between the "Dam-planned" and "No-change" option, is of equal importance X (Figure 2). Furthermore, the difference between the "Dam-reality" and "No-change" options of crop production is assigned a relative importance of 1.

Applying the rule of proportion twice allows us to determine the value of X and the relative importance of the difference between the "Dam-reality" and "No-change" options of electricity generation. Likewise, comparisons are carried out at inter-family and macro-criteria levels (columns B and C), each family or macro-criterion being represented by one of its bottom-level criteria. For instance, crop production, construction costs and the agricultural production value were compared at the inter-family level of the economic macro-criterion. On the other hand, construction costs, the intensity of water use and the increase in living standard were compared at the macro-criterion level.

The cumulative weight vector (column D) resulting from criteria-wise multiplication of the relative weights was then normalized (column E). As it is a theoretical assessment, assumptions to determine the weights, aiming at sustainability, were made by the authors. They are specified in Table 2. The swing

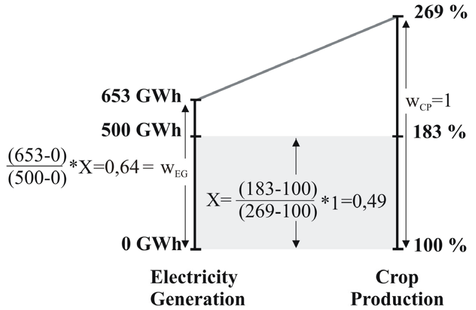


Figure 2. Swing weight approach

weight approach was carried out externally, the results then being loaded into mDSS.

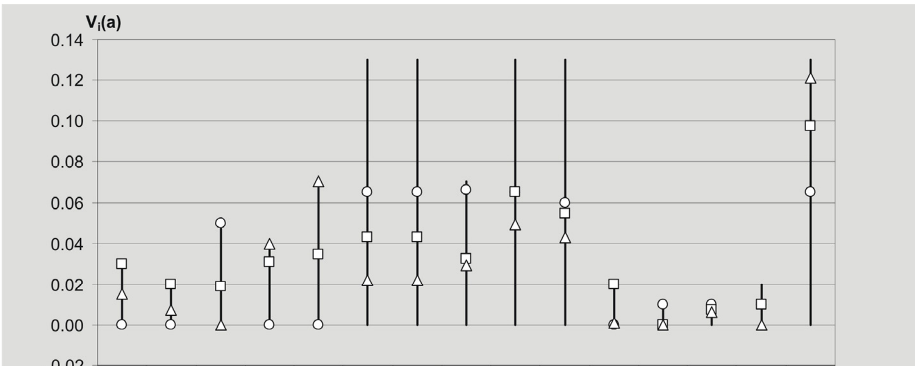
Subsequently, one out of three possible aggregation algorithms in mDSS was applied to merge the criteria-wise information into an overall ranking of the options. The simple additive weighting approach (SAW) was selected because, in general, it is easier to communicate within participatory processes. Because the method allows for compensation between good and bad scores of criteria, only little attention is given to the balance between criteria that is relevant with regard to sustainability. With SAW, the overall performance of option *a*, or *V(a)*, is calculated by summing up the products of $v_i(a)$, the value score of criterion *i*, and w_i, the weight of criterion *i*, considering all the *m* criteria:

$$V(a) = \sum_{i=1}^{m} w_i * v_i(a) \quad (1)$$

In the data set developed for the theoretical reproduction of the decision to build the Turkish Ceyhan Aslantas Project in the 1970s, the "Dam-planned" option (0.51) outranked the "No-change" option (0.47). The weighted profile graph (Figure 3) shows that the "Dam–planned" option, which is ranked first in overall performance, was only the better-rated option with regard to four of the five economic criteria and the living standard criterion. In addition, equal performance of the two options occurs for the criteria water quality and new diseases. In addition, the graph shows the importance of the "living standard" indicator among the list of criteria, which is partly due to the number of aspects considered in this criterion.

Sensitivity analysis

In order to find out how robust the results are with regard to changes in weights, mDSS provides a sensitivity analysis tool. The "most critical criterion" method is applied to calculate which criterion requires the minimum absolute value of change in order to reverse the options' rank order (Triantaphyllou, 2000). Reproducing the decision to build the Aslantas Dam, the criterion describing the number of people resettled



criterion (see table 1)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
○ NoDam	0.00	0.00	0.05	0.00	0.00	0.07	0.07	0.07	0.07	0.06	0.00	0.01	0.01	0.01	0.07
□ Planned	0.03	0.02	0.02	0.03	0.03	0.04	0.04	0.03	0.07	0.05	0.02	0.00	0.01	0.01	0.10
△ Reality	0.02	0.01	0.00	0.04	0.07	0.02	0.02	0.03	0.05	0.04	0.00	0.00	0.01	0.00	0.12
wi(a)*1	0.03	0.02	0.05	0.04	0.07	0.13	0.13	0.07	0.13	0.13	0.02	0.01	0.01	0.02	0.13
wi(a)*0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 3. Weighted profile graph with possible range of value scores

was identified as the most critical criterion. An increase of the current cumulative weight of 0.01 by +0.04 would make "No-change" the best-performing option. To achieve this, the scale describing the number of people resettled needed to be valued at 40 % of that of the "living standard" indicator, as compared to 10 % at present.

General perception holds that the larger a change is in comparison to the original weight, enough, that is, to cause a conversion of ranking, the less likely it is that this change will actually take place (relative sensitivity). To change the ranking of the options on the basis of the next sensitive criteria, which were the construction costs (+0.07) and the intensity of water use (+0.09), the required changes were even more fundamental.

Sustainability analysis

Based on the understanding that the three dimensions of sustainability – environment, economy and societal aspects – are inseparable, development is considered to be sustainable when it harmonizes the improvement of economic and social living conditions while aligning these considerations with the long-term protection of the natural living basis (UN-WCED, 1987). Sustainability has become one of the main objectives of all planning and management activities in water management (Loucks and Gladwell, 1999). For the notion of sustainability, both the balance between the three macro-criteria and the level of performance within each macro-criterion are relevant. The ratio of the overall performance of a macro-criterion on an option to the maximum possible performance of that macro-criterion gives an indication of its relative level of performance. It is decisive to use the relative instead of the absolute level of performance to ensure comparability among the macro-criteria. Calculating the average (arithmetic mean) and the standard deviation (S.D.) across the three macro-criteria – a step that is not yet encompassed in mDSS – shows which of the options performs best with regard to the three macro-criteria and which is most balanced. In compliance with the concept of sustainability, the arithmetic mean implies the equal importance of the macro-criteria. Allowing for compensation between the three macro-criteria, arithmetic mean and standard deviation are only jointly significant with regard to the notion of sustainability.

The option showing a high average level of performance with little deviation is the most preferable one. Comparing the "Dam-planned" and "No-change" options, the average values clearly confirm the ranking according to the overall score, while the standard deviations are almost equal (Table 3).

Discussion Of The Results Obtained

To analyze whether the decision would have been any different had the information on the project outcome been more complete at the time, a purely hypothetical comparison of the "Dam-reality" option with the "Dam-planned" and "No-change" options was carried out. As a result, the "Dam-reality" option was ranked last (0.43) behind the "Dam-planned" (0.51) and "No-change" (0.47) options. This means that, in theory, if the decision makers had known precisely what the outcome of the project was going to be and, of course, if they had adopted the decisional procedure and assumptions reported here, they might have decided not to build the dam. This was clearly impossible at the time of decision-making, but it brings attention to the relevance of uncertainty in the decision process.

Besides uncertainty of performance information (data availability, data accessibility, projections, etc.), uncertainty of preference information (value functions and weights) requires consideration. The capacity of the mDSS software may provide support to simulate alternative decision scenarios where high levels of uncertainty exist.

It may be interesting, for example, to abandon the assumptions inspired by the recent concept of sustainable development and try, by means of mDSS, to more closely simulate the hypothetical orientations of decision makers during the 1970s. In fact, at the time of decision-making, environmental impacts were not considered in any detail, and nor were decision makers formally required to do so (Agrin Co. Ltd., 2000).

These assumptions were transferred to the hypothetical comparison of the "Dam-reality" option with the "Dam-planned" and "No-change" options in mDSS. The exclusion of all environmental criteria results in the "Dam-planned" and the "Dam-reality" options at close scores of 0.67 and 0.64, outperforming the 0.38 score of the "No-change" option. That the Aslantas Dam is generally perceived to be uncontroversial (McCully, 2001) suggests that local decision makers, the general public and experts both in the past and at present may give only marginal attention to environmental aspects.

In recognition of this, the hypothetical comparison of the "Dam-reality" option with the "Dam-planned" and "No-change" options was extended, analyzing how the overall performance of the options changes according to the importance assigned to the macro-criteria in the decision tree. Preliminarily, the weights determined by the swing weight approach at the lowest level of the decision tree were aggregated and normalized to form relative and cumulative weights at the intermediate and uppermost levels.

Upon systematic analysis of all possible allocations of the weight distributions to the three macro-criteria, using a top-down approach, the weights at the lowest level were determined by multiplying the relative weights of all parent criteria. Subsequently, the ranking of the alternatives was determined for the developed range of weight sets.

Only three out of six possible rankings of the options occur. As the weights of the three macro-criteria are defined to sum to 1, the possible allocations of weights to the three macro-criteria outline a triangle in a three-dimensional coordinate plane. By means of this triangle the ranking of the alternatives can be presented as a function of the weight distribution to the three macro-criteria (Figure 4). The "Dam-planned" option's first rank turned out to be very stable except for very high allocations to the environmental macro-criterion. The ranking obtained through the hypothetical "Planned/No dam/Reality" comparison held only a very small section of all possible weight combinations. As long as economic and social aspects are considered equally important, the weight assigned to the environmental sector needs to be changed by ±10 % to change the overall ranking.

Further research will be needed to improve the interpretation of this type of diagram, in particular if more than two alternatives are compared. A better understanding of the composition of bottom-up and top-down weighting could support the understanding of sensitivity analysis for hierarchical decision trees.

Conclusions

Generally, decision analysis helps to provide structure to the thinking process, a language for expressing possible concerns, plus a way of combining different perspectives. Hence, the emphasis must be on the process, not on the act or the outcome, as stated by Belton and Stewart (2002). Mulino DSS has proven to be a useful tool supporting decision analysis both in general and in particular with regard to the large dam context of this study:

- In the exploratory study conducted on the Aslantas Dam to test the applicability of the MULINO method, the DPSIR approach has been consistently supportive in structuring decision-making, while the multi-criteria assessment methodology provided effective guidance through the decision-making process, as well as through sensitivity and sustainability analysis.
- Scenario analysis capabilities proved to offer concrete potentials for exploration of the possible

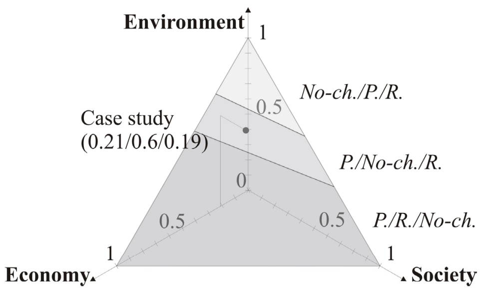


Figure 4. Ranking obtained by weight variation

effects of uncertainty and different perspectives on the final decision. The sustainability analysis, i.e. the average and standard deviation analysis of criteria, allowed for the exploration of compensatory effects of the SAW aggregation methodology.
- mDSS provided support for the management of information that is characterized by diversity: long time series, large spatial areas, multi-disciplinarity, uncertainty and varying units.
- By helping to explicitly disclose the assumptions and interests involved in a decision context, mDSS obtains a two fold benefit. Firstly, the decision process is made transparent. Secondly, it allows to simulate and explore alternative political or cultural visions of a problem from both *a priori* and *a posteriori* perspectives.

On the other hand, advances in methodology with regard to problem structuring, performance analysis and sensitivity analysis through further research would strengthen the applicability of mDSS in assessing sustainability. In particular, focus needs to be on several aspects:

- In the intelligence phase, problem structuring needs to be revised so that descriptive as well as value-oriented, normative criteria can be identified in order to foster the analytical potential of the mDSS tool with regard to sustainable development. The criteria selected in the conceptual phase represent the cause-effect chains characterizing the functioning of the system. The WCD's strategic priorities and guidelines on specific sustainability criteria are not respected if equity issues, the balance between economic, environmental and social systems, as well as rights affected and risks imposed are seen to be lacking. In general, problem structuring approaches are chiefly guided by the choices among alternatives instead of being driven by the values society cares about (Keeney, 1992);
- In the design phase, MCA requires a single value to represent the lifetime performance of a criterion induced by a given option. The developments with and without a project need to be compared, not simply the state before and after a project. Aggregating the performance over time in a single value requires the avoidance of any influence of time preference, i.e. valuing present benefits and costs more than future ones, while at the same time deliberately considering the increasing uncertainty connected to future values. Instead, for the sake of transparency, the potential of introducing separate analysis matrices representing the life phases of a project should be analyzed;
- In the choice phase, what needs to be considered in order to add to the sensitivity analysis of single criterion weights is the systematic variation of multiple criterion weights as well as of performance values and value functions. Possible starting points for future advancements in mDSS are the different causes of uncertainty influencing multi-criteria analyses, as shown in Figure 5, i.e. the main sources for the ambiguity of options ranking. Even if the individual criteria can be predicted with a certain degree of accuracy, the methodology of multi-criteria assessment is challenged by the impact of these different types of uncertainties on the accuracy of the overall result.

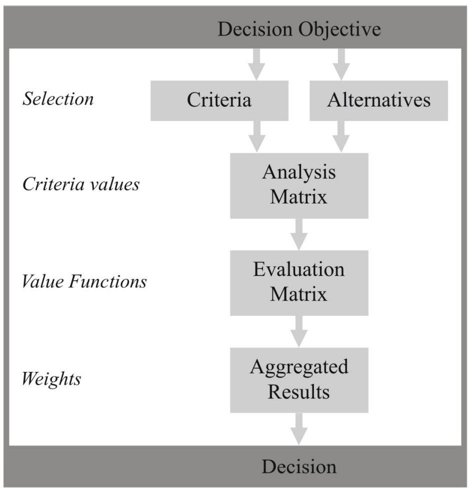


Figure 5. Causes of uncertainty in multi-criteria analysis

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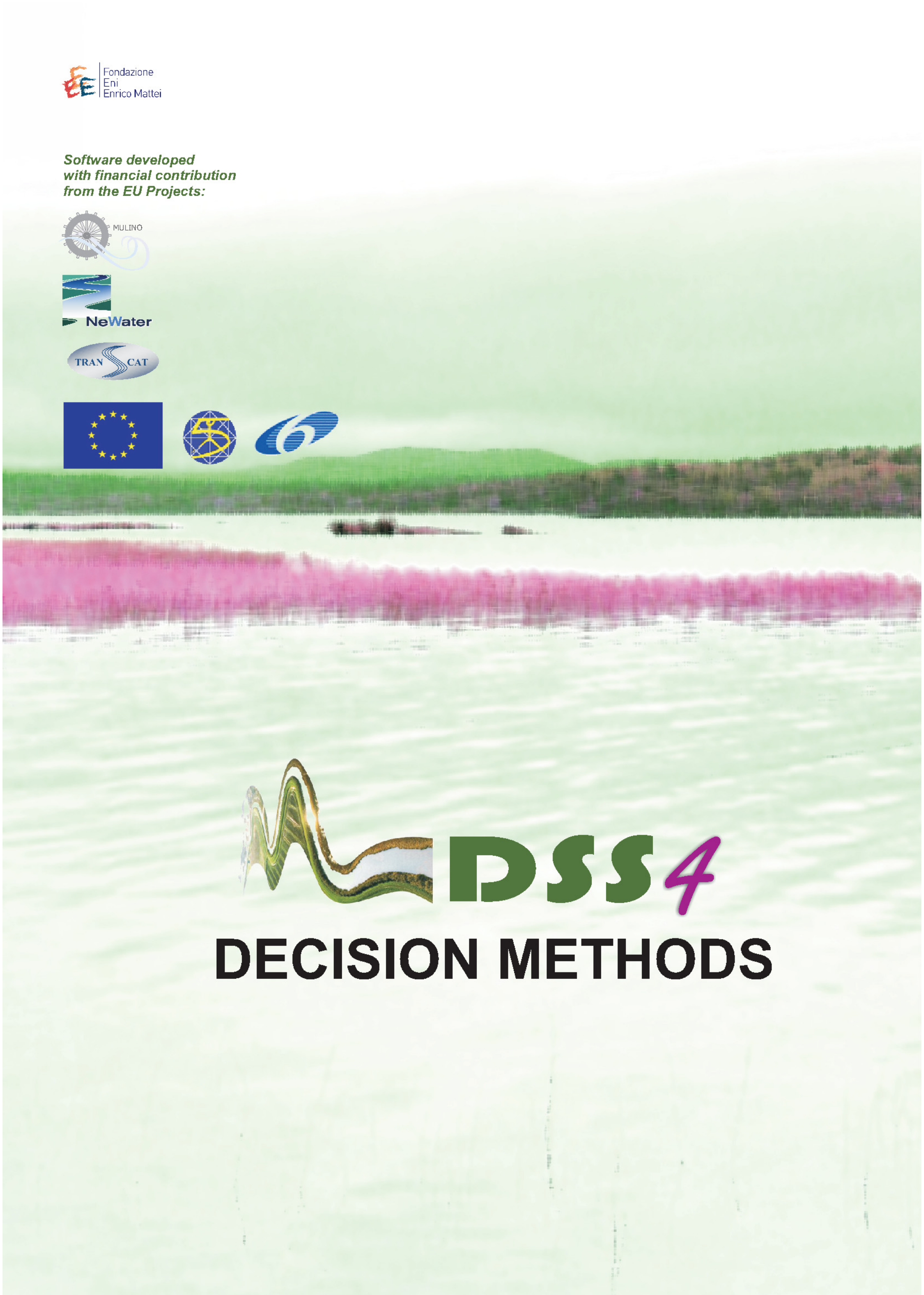
4.7 MDSS4 DECISION METHODS

mDSS Decision Methods. Carlo Giupponi, Jaroslav Mysiak. Y Jacobo Feás.

http://www.netsymod.eu/mdss/userguide.pdf


Fondazione
Eni
Enrico Mattei
Software developed
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from the EU Projects:
MULINO
NeWater
TRAN
CAT
DSS4
DECISION METHODS

Document information

Authors: Carlo Giupponi, Jaroslav Mysiak and Jacobo Feás

This document explains the functional design of the mDSS4, a generic decision support system developed to assist the implementation of the Water Framework Directive and the development of the River Basin Plans. The multicriterio decision analysis (MCA) methods implemented in the mDSS4 are described in details and some examples are used to show how different methods work.

The software and further resources to which this document makes reference are available from: http://www.feem.it/mulino and http://www.netsymod.eu.

This document was written for the mDSS version 4.1, released in October 2006. Further information about the software can be found in "Users' guide " and in the practical tutorial "mDSS Tutorial".

"The world moves into the future as a result of decisions, not as a result of plans. Plans are significant only insofar as they affect decisions ... if planning is not part of a decision making process, it is a bag of wind, a piece of paper, and worthless diagrams."

[Boulding 1974]

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1 INTRODUCTION

1.1 NETSYMOD

The NetSyMod methodology is the result of several years of research in the field of environmental evaluations and decision making carried out at FEEM within the Natural Resources Management Research Programme. It is intended to become a flexible but comprehensive methodological framework and a suite of tools aimed at facilitating the involvement of stakeholders or experts in various contexts and in particular in those decision making processes (DMPs) characterised by the participation of multiple actors. In such context decision is intended in a broad sense, including any process in which a choice has to be taken by examining the available information on a given problem. The problem itself, the information, and the choice are defined with the contribution of different actors. The implementation field of NetSyMod is in general the management of natural resources, with two main categories of applications which may be also encountered together in the same case: (i) the involvement of experts in a decision or an evaluation of an environmental problem requiring diversified fields of expertise, and (ii) the involvement of interested actors in a generic participatory process dealing with the management of environmental resources. This methodological approach can be applied in the following cases:

- Participatory planning and decision making processes for Integrated Water Resource Management;
- Transboundary management and negotiation;
- Contribution of experts to the formalisation of a shared knowledge base and of integrated models.

In the field of integrated water resources management, there is an urgent need to apply and develop new methodologies for linking formal and analytical methods and participatory stakeholder based approaches. In recent years, concern about the operational limitations of participative approaches and tools has been expressed. Therefore, before starting a participatory approach it is of utmost importance to design it carefully taking into consideration all the negative effects and the shortcomings which can follow. The transparency of the process should also be guaranteed in order to make it more reliable. The use of scientific methodologies, which allow the identification of the actors to be involved in the process assuring the objectivity and impartiality of the choice, should help the definition of more sound participatory approaches.

NetSyMod is targeted to contribute to the adoption of improved Decision Support System (DSS) tools in decision/policy making processes related to environmental matters. In fact, building a decision support system tool in a participatory way improves the performance of the tool, increases its acceptability, and, ultimately, the acceptability of the decisions taken with its support. The process of participatory modelling – as much as participatory planning – does however have many pitfalls, which may not only frustrate the efforts of participatory planning, but also, in some cases, lead to counterproductive results. This is the case if, for instance, during the problem conceptualisation phase of participatory modelling – arguably the key step in building a DSS – key stakeholders are not consulted, and/or power relations are not managed in an appropriate way.

This methodological approach places great emphasis on the integration and implementation of state-of-the-art approaches in the field of modelling from the more traditional approaches of bringing simulation models in the decision process through the development of ad hoc decision support systems, to the more innovative creative thinking approaches for participative modelling design.

The main components common in all the envisaged applications of the methodology are:

• Actors Identification (AI) for identifying all potential stakeholders/experts involved or affected by the decision under examination. The process proposed to fulfil this objective is a simple approach based on the organisation of brainstorming meetings and on the use of a snowball techniques.

• Social Network Analysis (SNA) which aims at assessing the reciprocal relationships among actors within their local social networks. Characterising the power structure prevalent in the selected group of actors, SNA should ensure that the participatory modelling and/or planning process is not hijacked by powerful groups, but rather, it is truly representative of the whole sample – and population – of interested parties.

• Creative System Modelling (CSM) which provides means for facilitating the process of participatory modelling and, more specifically, for eliciting knowledge and preferences from actors. The key actors chosen in the previous steps of the NetSyMod approach will take part in a participatory workshop during which Cognitive Mapping techniques most suitable for the specific case will be applied.

• Analysis of Options (AoO), in which the participatory approach is brought in the field of decision support envisaging the use of specific computer support tools.

In the first two phases the –iterative– identification of actors (stakeholders, experts,...) to be involved has to be carried out and their reciprocal relationships within social networks to be assessed. Once a sort of community of interested parties has been formed, mental modelling and techniques in the field of cognitive mapping should be applied by the management group to produce a shared model (i.e. a simplified representation of the part of the reality of interest). In other words a formal description of the system in question and its causal links, to which the problem pertains, has to be developed in order to be commonly understood and recognised by the actors involved. The systems of interest are those in which human activities interact with each other and with the natural resources. The main assumption of NetSyMod is that creative system modelling can provide not only a common ground for mutual understanding between the involved parties, but also a scientifically sound basis for the development of effective decision support systems. The latter may in turn be based upon complex mathematical models, which may find in the methodology proposed an interface for easier communication with the interested public. The final phase of decision support may be of different nature, from cases in which group decision making techniques are applied for supporting choices between a given set of alternative options, to others in which the opinions of experts have to find a common ground in the debate about a specific problem.

1.1.1 ACTORS' ANALYSIS

What? [Description of step]

This initial phases identifies all potential stakeholders/experts involved or affected by the decision under investigation, and singles out those who should take active part in the decision making process.

How? [Key methodological considerations]

First of all, it is necessary to identify all potential stakeholders/experts involved in, or affected by, the decision to be undertaken. Within the NetSyMoD framework, a task force group is set up for this purpose, which, through a combination of brainstorming meetings and a modified snowball sampling technique, carries out this task.

When all the relevant actors have been identified, a Social Network Analysis is undertaken, with the aim of assessing the reciprocal relationship among actors. Through the use of questionnaires and interviews, the SNA will allow the identification of key actors, the assessment the power structure among the actors, and the characterisation of their role and position with respect to the decision to be taken.

Why? [Main outputs]

SNA ensures that the participatory modelling and/or planning process is not hijacked by powerful groups, but rather it is truly representative of the whole spectrum of interests and positions. There are thus three main outputs from the SNA phase, which will be an input into the preparatory phase for the CSM workshop.

1. A list of key stakeholders/experts to be involved in the next phases of NetSyMoD. This will limit the number of participants to a manageable size, and ensure that no important actors are left out of the exercise.

2. The analysis of power will highlight potentially problematic actors and relations, whom the facilitator will need to actively manage during the creative system modelling workshop.

3. A conflict analysis on the basis of position and roles of actors within the network, with the purpose of identifying key alleys and/or opponents, and actors who are opinion setters.

1.1.2 PROBLEM ANALYSIS

What? [Description of step]

In this phase the problem (or conflict) at hand is scrutinised from various perspectives and viewpoints. The environment in which the problem is embedded is explored and the relevant factors identified.

How? [Key methodological considerations]

The problems faced by natural resource managers are complex and their drivers interwoven. It is necessary to identify the most relevant aspects, by focusing on which the major changes can be attained. The exploration of the problem include analyses of legal and institutional frameworks, as well as the economy on various spatial levels and the state of environment. Future development of main drivers and pressures are simulated using models under alternative scenarios.

Different stakeholders (identified in previous step – Actor analysis) hold different perceptions and beliefs about what are the causes of the problem or how it should be tackled. Different techniques have been developed to surface tacit knowledge and deeply held beliefs, including conflict assessment, problem structuring methods, discourse analysis. The individual perspectives are further elaborated in the next step (Creative system modelling) to facilitate collective learning and shared (agreed) boundaries of the problem.

Why? [Main outputs]

The problem analysis phase typically ends with

1. A list of most relevant drivers governing the perception of the problem at hand

2. Sketch of cause-effect relations between various drivers, identified and explored using multiple methods and models

3. A set of scenarios regarding the future development of the main drivers and cause-effect relations

4. A extensive list of indicators against which the performance of policy measures should be measured

1.1.3 CREATIVE SYSTEM MODELLING

What? [Description of step]

A shared model of reality is needed for the correct evaluation of policy options. Creative System Modelling (CSM) techniques facilitate the process of participatory modelling and elicitation of knowledge and preferences from actors, thus building a common understanding of the problem.

How? [Key methodological considerations]

The key actors identified in the previous step will take part in a participatory workshop, during which cognitive mapping techniques (such as the Hodgson's hexagon method or a revised Delphi technique) will be used to develop a shared model of the decision problem.

The CSM workshop can have two main aims, depending on the case at hand:

i. building a shared model of the problem, based on cause-effects chains and using the DPSIR conceptual model (Driving Force, Pressure, State, Impact, Response); or

ii. developing shared scenarios, depicting the potential evolutions of the system over time, or under different policies.

The CSM will also serve the purpose of identifying shared evaluation criteria, and eliciting individual and group weights, necessary for the evaluation of policy options through multicriteria analysis.

Why? [Main outputs]

Creative system modelling provides not only a common ground for the mutual understanding among the parties involved, but also a scientifically sound basis for the development of effective decision support systems (DSSs).

The cognitive map of the decision problem, or the related scenarios, will be the basis for the analysis of options:

- the shared mental maps elicited at the CSM workshop will be the underlying modelling framework for tailoring mDSS to the specific needs;

- the workshop will provide qualitative and/or quantitative indicators to be used in the choice phase in mDSS;

- the workshop may also lead to a quantitative assessment of these indicators, in addition to their identification.

1.1.4 DSS DESIGN

What? [Description of step]

In this phase numerous tools and information (knowledge) produced in previous steps in assembled into a toolbox or framework. This is necessary to manage the information flow between various process phases, including exchange, transformation, integration, validation and documentation of gathered knowledge.

How? [Key methodological considerations]

Many of the previous analyses employ computer-based tools such as databases (and data management systems), visualisation components, and simulation models. Different tools are frequently assembled into a comprehensive Decision Support Systems, normally employing various interconnected and adapted components, controlled by an user interface. This phase address all activities related to the development of interoperable and useable software components; and collection of well documented and easily exchangeable data sets (including spatial data and time series).

Why? [Main outputs]

1. Seamless data flow between various tools and software component

2. User interface which guides user though various stages of the NetSyMod process

3. Quality assurance regarding the integration of different components

4. Documentation and report facilities which explain the process and facilitate the interpretation of results

1.1.5 POLICY EVALUATION

What? [Description of step]

Policy evaluation consists of choosing one (or more) policy measure from a set of mutually exclusive alternatives, or producing their complete ranking. Numerous methods and techniques have been developed in decision theory to make explicit (transparent) value judgements and assess the extent to which different policies contributed to achieve the pursued goals and objectives.

How? [Key methodological considerations]

Decision models (DM) result from the systematic exploration and negotiation of a 'problem', including its existence, boundaries and structure. DM comprise alternative courses of actions (policies or policy measures); decision goals - translated into more tangible evaluation criteria - against which the policies are weighed; and preferences, which describe how well the policies satisfy the objectives.

There are normally several candidate policies; for example, high nitrate pollution can be tackled by introducing financial incentives, changing nutrient management in farms, by protecting littoral vegetation and favouring phytodepuration, or by improving the effectiveness of waste water treatment plants, WWTP). Binary (yes/no) choices, such as whether to adhere to the Kyoto protocol for reducing greenhouse gas emissions are frequently indicative of escalating conflicts due to incommensurable ethical principles, values and interests. Goals may refer to competing targets, e.g. macro-economic developments vs. social impact; favouring different policies so that no single option outperforms all others. In these situations, decision makers may be a priory uncertain (undecided) about what policy action is most appropriate. This indecisiveness is a result of the diversity of decision outcomes, which are not uniformly distributed in space and time (e.g. different policy impacts on upstream vs. downstream water users; WWTP extensions may have an earlier impact on nitrate concentration than land use changes) or the values attached to them. Uncertainty in the outcomes of a choice poses yet another challenge for decision making.

The trade-offs or preferences are value judgements, which are frequently not observable and must be revealed or approximated. Such uncovered preferences are context specific and depend on the description and framing of a problem, and how the questions are formulated. For example, to assess the environmental costs of irrigation, one must consider the value of wetlands and riverine ecosystems deprived by water abstraction. These values, regardless of whether they are in monetary terms or relative utility, may be difficult to approximate as the results depend on the respondents' prior knowledge or on what they think others would approve. In situations involving uncertainty, preferences are formed over probabilities of possible outcomes of the policies and integrated into the decision model. These preferences embody attitudes towards risk (risk aversion vs. risk seeking vs. risk neutrality), defined according to the value individuals attach to the uncertain outcomes of a decision.

Why? [Main outputs]

Decision methods help to avoid inconsistencies underlying judgement and choice, and make decisions more compatible with normative axioms of rationality. Furthermore, if combined with deliberative techniques, decision methods render policy processes transparent and informed the perspectives or viewpoints of all actors. This is translated into a higher acceptance of the policies.

1.1.6 ACTIONS AND MONITORING

What? [Description of step]

In this phase the implementation of the decisions is monitored. This includes the progressive examination of the assumptions about the future development as well as the revision of the choices made upon these assumption.

How? [Key methodological considerations]

Why? [Main outputs]

2 INTRODUCTION TO THE MULTICRITERIA DECISION AID

A ***decision problem*** is considered to exist, when a planner or a decision maker (DM) perceives a discrepancy between the current and desired states of a system, and when (i) the DM has alternative courses of action available; (ii) the choice of action can have a significant effect on this perceived difference; and (iii) DM is motivated to make a decision, but he is uncertain a-priori as to which option should be selected. ***Multicriteria decision aid*** (MCA) is a branch of decision theory which deals with decision problems characterised by a number of evaluation criteria. Two fundamental parts of MCA are (i) *Multiple Attribute Decision Making* (MADM), and (ii) *Multiple Objective Decision Making* (MODM). The former approach requires that the choice (selection) be made among a limited number of options which are described by their attributes.

The second approach allows the number of potential options to be nearly indefinite. The options are not defined explicitly. Instead, MODM provides a mathematical framework for designing a set of decision alternatives.

Definitions

Preference is a decision maker's notion about the available options.

Options[1] represent the different choices of action available to the decision maker. *Feasible options* must fulfil the satisfaction level (constrains) given by the decision maker for a set of criteria. A *non-dominated option* refers to the one that is, at least equal in all criterion scores and at least is better in one criterion than other (dominated) options.

A ***criterion*** is a standard of judgement to test the desirability of an option. In MCA the concept of a criterion includes both *attributes* and *objectives* referring to two main directions: *multi-attribute* and *multi-objective* decision-making. An *attribute* is a qualitative or quantitative property that is measurable and relevant to a decision. An *objective* is a statement about the desired state. Functionally related to the attributes, the objectives indicate the directions of improvement (e.g. an objective may be formulated as: minimising the water pollution).

Decision matrix is a (M x N) matrix in which the element x_{ij} indicates the performance of the option a_i evaluated in the terms of the decision criterion c_j. While the "raw" performances expressed in different non comparable units and scales are represented in the so called *analysis* matrix, the relative performance (u_{ij}) is constituted by the preference mapping using a value/utility function and expressed in the same scale as the *evaluation* matrix.

Value function (u) is a mathematical representation of human judgements. It translates the performances of the options into value scores, which represent the degree to which a decision objective is matched. I.e.:

$$u(a) > u(b) \Leftrightarrow a \succ b$$
$$u(a) < u(b) \Leftrightarrow a \prec b$$
$$u(a) = u(b) \Leftrightarrow a \sim b$$

where a, b …options
u() …value function
$\succ$ … is prefered
~ …is indifferent

3 MULTICRITERIA DECISION ANALYSIS

3.1 BASIC STEPS OF MCA

Figure 2 shows the basic steps of multicriteria decision analysis as implemented in the mDSS. The decision process starts with problem structuring during which the problem to be solved is explored and available information is collected. The possible options – responses in terms of the DPSIR framework – are defined and criteria aiming at evaluation of their performance are identified. In the next step the options' performance in terms of the criteria scores is modelled. As a result a matrix – called analysis matrix – is constructed. The analysis matrix contains the raw options' performance with different criteria scales.

[1] In this document the term "option" is used where many theorists would use the term "alternative".

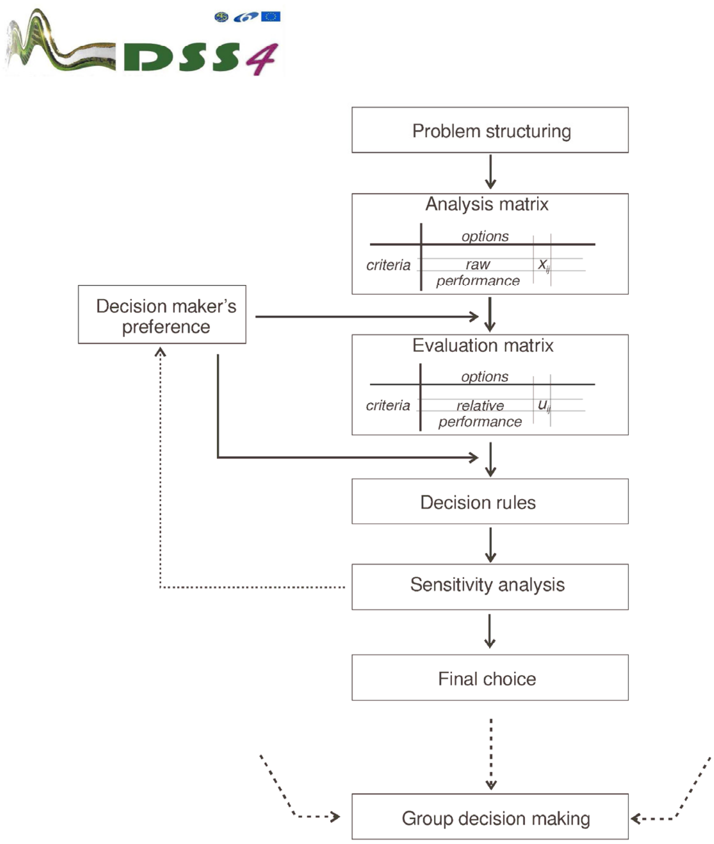

Fig. 1: The basic steps of the MCA that is implemented in the mDSS

Before any aggregation may start, the options' performance with regards to different criteria have to be made comparable. During the standardisation procedures, or at least by applying a value function, the scores are transformed to values on a uniform scale. Since a simple standardisation allows only the transformation of a given value range to a standardised one [0,1], the value function includes human judgements in the mathematical transformation. A value function translates the performance of an option into a value score, which represents the degree to which a decision objective is matched.

Since the main aim of a multicriteria decision analysis is to reduce multiple option performances into a single value to facilitate the ranking process, the heart piece of any MCA decision rule is an aggregation procedure. The large quantity of known decision rules differ in the way the multiple options performance are aggregated into a single value. There is no single method that is universally suitable for any kind of decision problem, the decision maker has to choose the method which best corresponds with his purpose. Finally, a sensitivity analysis examines how robust the final choice is to even a small change in the preferences expressed by the decision maker.

In a situation where there are several decision makers involved in the decision process, the individual choices are to be compared and an option is to be chosen, which represents the group compromise decision.

3.2 GENERATING THE ANALYSIS MATRIX

The *analysis matrix* (*M x N: M* options and *N* criteria) is to be built from the environmental indicators identified in the conceptual phase. The cells of the matrix relate to the *option-criterion* pairs and contain the outcomes or consequences for a set of options and a set of evaluation criteria.

In spatial decision-making, the options are a collection of points, lines, and areal objects with associated attributes. The decision outcomes, as in figure 3b-c, may have spatial extensions. For example, in the case of two-dimension a spatial extended decision outcomes (figure 3c), a cell of the decision matrix corresponds to a *map*, which contains the spatially distributed consequences of an option with regards to a criterion. Different to the case of non-dimensional (value- or point-like outcomes, figure 3a) consequences, an additional aggregation must be done.

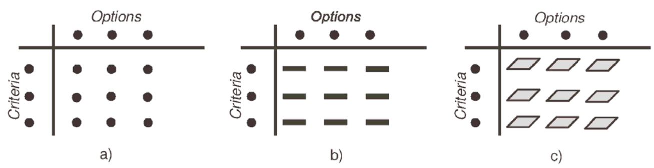

Fig. 2: Different dimensions of decision outcomes: spatial dimension 0 (a); 1 (b) and 2 (c).

3.3 STANDARDISING THE ANALYSIS MATRIX

During the standardisation the criterion values expressed in different measurement units are transformed into a common scale, which allows their comparison. The mDSS utilises a linear scale transformation method - the *score range* method. The method doesn't maintain the relative order of magnitude, but scales the raw options' scores precisely in the interval [0,1] (formulas 1-2).

$$x'_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \quad \textit{for a criterion to be maximized} \qquad 1.$$

$$x'_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \quad \textit{for a criterion to be minimized} \qquad 2.$$

A value x_{ij} corresponds to the option *(i)* and the criterion *(j)*. The notations $x_j^{\min}$ and $x_j^{\max}$ means the lowest and largest score of the *j-th* criterion.

The TOPSIS decision rule (see section 2.4.6) uses vector normalisation (formula 3.). This method has a particular property of producing vectors (the rows of the decision matrix) with the same Euclidean length (equal 1).

$$x'_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} \left(x_{ij}\right)^2}} \qquad 3.$$

3.4 MODELLING VALUE FUNCTION

The value function is another way of transforming the raw criteria scores into a common scale. Hovever, it allows the preferences of the decision maker to be considered during the transormation.

Decision theory provides a theoretical framework for representing the decision maker's preferences about the options' performance. In order to make them more "computational", the preferences are mapped by the value/utility function (*u*). A value/utility[2] function maps the preference about two options *a* and *b* ($a \succ b$: *a* is preferred *b*) in a numerical relation *u(a) > u(b)*.

There are several methods for the estimation of the value functions (see figure 4). The mDSS utilises the direct rating method by which the decision maker immediately assigns a value to each criterion score. The shape of the value function may be selected from the implemented set of value functions and only their parameters must be specified. In figure 5 and formulas 9-11 some widely used types of value function are shown.

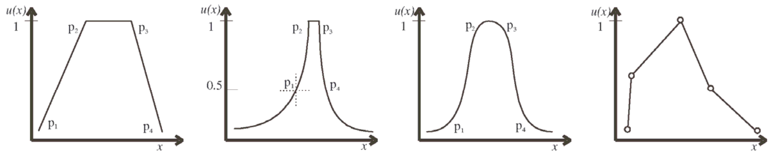

Fig. 3: Some kinds of value function: (a) linear; (b) j-shaped; (c) Sigmoidal: (d) user defined.

The mDSS supports the piece-linear definition of the value function by the user (figure 4d).

3.5 MODELLING CRITERIA WEIGHTS

Decision problems involve criteria of varying importance to decision maker. The criterion weights usually provide the information about the relative importance of the considered criteria. There are many techniques commonly used for assessing the criterion weights such as ranking and rating methods, pairwise comparison and trade-off methods.

Ranking methods use the rank order on the considered criteria. As the rank order describes the importance of the criteria, the information describing them (rank number r_i) is used for generating numerical weights.

[2] The term *value function* is used in the context of decision under certainty. The *utility function* refers to the situation under risk consideration, i.e. when the outcomes are associated with a probability.

$$w_i = \frac{(n - r_i + 1)^p}{\sum_{k=1}^{n} (n - r_k + 1)^p}$$

n … number of criteria

r_i … rank number of criterion i

4.

p … parameter describing the weights distribution

The parameter p may be estimated by a decision maker through interactive scrolling (as in table 1) or with the help of formula 12 using the weight of the most important criterion as an input from the decision maker. For p = 0 results to equal weights. As p increases, the weights distribution becomes steeper. Table 1 shows the estimated weights for some values of p.

		Parameter p						
	Rank	0	0,5	1	2	3	.	10
Most important criterion	1	0,2	0,26	0,33	0,45	0,55	.	0,89
.	2	0,2	0,23	0,26	0,29	0,28	.	0,09
.	3	0,2	0,2	0,2	0,16	0,12	.	0
.	4	0,2	0,16	0,13	0,07	0,03	.	0
Less important criterion	5	0,2	0,11	0,06	0,01	0	.	0
Sum		1	1	1	1	1	.	1

Table 1: The behaviour of the generated numerical weights depending on the parameter p of the rank component method

Pairwise comparison method was developed by SAATY (1980, quoted by MALCZEWSKI 1999) in the context of his decision rule called *Analytic Hierarchy Process*. The method involves pairwise comparisons to create a ratio matrix. Through the normalisation of the pairwise comparison matrix the weights are determined.

The method uses an underling scale with values, from 1 to 9 for example, to describe the relative preferences for two criteria. The result of the pairwise comparisons is a reciprocal quadratic matrix (as in table 2).

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	…may be used for interpolation between the

	C_1	C_2	C_3	C_4
C_1	1	4	7	5
C_2	1/4	1	1/3	9
C_3	1/7	3	1	5
C_4	1/5	1/9	1/5	1

I. II.

Table 2: Example of pairwise comparison: (I) Scale for pairwise comparison; (II.) pairwise comparison matrix between 4 criteria (C_1-C_4)

Using the pairwise comparison matrix $A \in \mathbb{R}^{n \times n}$ the weights w_j may be determined as below:

1. Estimate the maximum eigenvalue λ_{max} of the comparison matrix, which fulfil formula 5

$$\det(A - \lambda \times I) = 0 \qquad 5.$$

2. Determine the solution $\tilde{w}$ as in formula 6

$$\begin{aligned} (A - \lambda \times I) \times \tilde{w} &= 0 \\ \tilde{w_i} &\geq 0 \end{aligned} \qquad 6.$$

3. Normalise the $\tilde{w}$ by formula 7

$$w_j = \frac{\tilde{w}_j}{\sum_{i=1}^{n} \tilde{w}_i} \qquad 7.$$

After the weights have been determined, the consistency of pairwise comparison must be evaluated. The procedure of consistency test may be found in Annex 3.1.

The Saaty method deals with the consistency of the pairwise comparison matrix. A consistent matrix means for example if the decision maker says a criterion ***x*** is equally important to another criterion ***y*** (so the comparison matrix will contain value of a_{xy} = 1= a_{yx}), and the criterion ***y*** is absolutely more important as an criterion ***w*** (a_{yw} = 9; a_{wy} = 1/9); then the criterion ***x*** should also be absolutely more important than the criterion ***w*** (a_{xw} = 9; a_{wx} = 1/9). Unfortunately, the decision maker is often not able to express consistent preferences in the case of multiple criteria. Saaty's method measures the inconsistency of the pairwise comparison matrix and sets a consistency threshold which should not be exceeded (for details about consistency of pairwise comparison matrix see the Annex 3.1).

3.6 DECISION RULES

Decision rules aggregate partial preferences describing individual criteria in a global preference and then rank the options. The decision rules chosen for implementation in the *m*DSS include (i) *simple additive weighting* (SAW), (ii) *order weighting average* (OWA), and (iii) an *ideal point method* (TOPSIS). These decision rules cover a wide range of decision situations and may be chosen by the decision maker according to the specifics of a given decision problem.

- SAW is one of the most popular decision method because of its simplicity. It assumes additive aggregation of decision outcomes, which is controlled by weights expressing the importance of criteria.

- The OWA is being used because of its potential to control the trade-of level between criteria and to consider the risk-behaviour of the decision makers.

- Ideal point methods like TOPSIS order a set of options on the basis of their separation from the ideal solutions. The option that is closest to the ideal positive solution and furthest from the negative ideal solution is the best one.

3.6.1 SIMPLE ADDITIVE WEIGHTING (SAW)

Simple additive weighting is a popular decision rule because of its simplicity. It uses the additive aggregation of the criteria outcomes (Formula 8).

$$\Phi_{SAW}(a_i) = \sum_{j=1}^{n} w_j \times u_{ij} \qquad w_j \text{ .. criterion weights} \tag{8.}$$

Considering a simple example of two options and three criteria

	w_i	a_1	a_2
c_1	0.4	0.2	0.8
c_2	0.4	0.5	0.11
c_3	0.2	0.9	0.25

The SAW aggregation is performed as following:

$\Phi_{SAW}(a_1) = 0.2 * w_1 + 0.5 * w_2 + 0.9 * w_3 = 0.2 * 0.4 + 0.5 * 0.4 + 0.9 * 0.2 = 0.46$

$\Phi_{SAW}(a_2) = 0.8 * w_1 + 0.11 * w_2 + 0.25 * w_3 = 0.8 * 0.4 + 0.11 * 0.4 + 0.25 * 0.2 = 0.414$

Since $\Phi(a_1) = 0.46 > 0.414 = \Phi(a_2)$, the option a_1 is preferred - $a_1 \succ a_2$

***Example 1**: Aggregation using simple additive weighting decision method*

3.6.2 ORDER WEIGHTING AVERAGE (OWA)

The Ordered Weighted Averaging (OWA) operator provides continuous fuzzy aggregation operations between the fuzzy intersection (MIN or AND) and union (MAX or OR), with weighted linear combination falling midway in between. It adopts the logic of Yager (1988) and can achieve continuous control over the operator degree of ANDORness and the degree of tradeoff between criteria.

The criteria are weighted on the basis of their rank order rather than their inherent qualities. By so doing the weights – called order weights - are applied to the criteria according to the rank order across their scores. For a given option, the order weight $\boldsymbol{ow_1}$ is assigned to the criterion with the lowest score, order weight $\boldsymbol{ow_2}$ to the criterion with next higher-ranked scores, and so on. Consequently, an order weight $\boldsymbol{ow_i}$ may be assigned to different criteria by two options $\boldsymbol{o_1}$ and $\boldsymbol{o_2}$, depending on the rank order of their scores.

$$\Phi_{OWA}(a_i) = \sum_{k=1}^{n} ow_k \times b_k \tag{9.}$$

where b_k denotes the k-*th* lowest score of the options ***i*** (u_{ij})

Trade-off means that a very low score in one criterion may not be compensated with a very high score in another one. The SAW decision rule described in chapter 2.6.1 allows full tradeoff. The MAXIMAX decision rule, in which the decision maker selects the option with the maximal scores in the best criterion, and the MAXIMIN rule, by which the option with the best scores in the worst criterion is selected, don't allow any tradeoff as the decision is made according only to one criterion.

OWA may be characterized as a control allowing an aggregation between the MAXIMAX, MAXIMIN and SAW extremes. In the case of 3 criteria the set of order weights [1, 0, 0] assigns the extreme importance to the lowest criterion score and corresponds to the MAXIMIN rule. The order weights [0, 0, 1] in contrast assign the extreme importance to the largest criterion score and correspond to the MAXIMAX rule. Equally distributed order weights [0.33; 0.33; 0.33] apply some importance to each rank and don't change the options ranking obtained from the SAW rule.

Considering two options and three criteria as in the table below

	a_1	a_2
c_1	0.2	0.8
c_2	0.5	0.11
c_3	0.9	0.25

The order weights [ow_1 = 0.5; ow_2 = 0.2 ; ow_3 = 0.3] will be assigned to the criteria for each option as following:

	a_1	a_2
c_1	ow_1	ow_3
c_2	ow_2	ow_1
c_3	ow_3	ow_2

The OWA aggregation is performed according to the previous table:

$\Phi(a_1) = 0.2 * ow_1 + 0.5 * ow_2 + 0.9 * ow_3 = 0.2 * 0.5 + 0.5 * 0.2 + 0.9 * 0.3 = 1.4$

$\Phi(a_2) = 0.11 * ow_1 + 0.25 * ow_2 + 0.8 * ow_3 = 0.11 * 0.5 + 0.25 * 0.2 + 0.8 * 0.3 = 0.345$

Since $\Phi(a_1) = 1.4 > 0.345 = \Phi(a_2)$, the option a_1 is preferred - $a_1 \succ a_2$

Example 2: *Aggregation using the order weighting averaging.*

The ANDness, ORness and TRADEOFF characteristics of any particular distribution of the order weights may be calculated using the formulas (10-12).

$$ANDness = (1/(n-1))\sum_{i=1}^{n}((n-i)W_{order\,i}) \qquad (10.)$$

$$ORnees = 1 - ANDness \qquad (11.)$$

$$TRADEOFF = 1 - \sqrt{\frac{n\sum(W_{order\,i} - 1/n)^2}{n-1}} \qquad (12.)$$

n .. number of criteria

i .. criterion rank order

$\boldsymbol{W_{order\_i}}$ .. order weight of ***i***-th criterion

In table 3 these characteristics are calculated for a selected set of order weights.

	Order weights				
	ow1	**Ow2**	**ow3**	**ANDness**	**TRADEOFF**
MAXIMIN =	1	0	0	1	0
	0,9	0,1	0	0,95	0,15
	0,8	0,2	0	0,90	0,28
	0,5	0,5	0	0,75	0,50
	0,5	0,3	0,2	0,65	0,74
	0	1	0	0,50	0,00
	0	0,8	0,2	0,40	0,28
MAXIMAX =	0	0	1	0,00	0,00
SAW =	0,33	0,33	0,33	0,50	1

Table 3: Characteristics of selected sets of order weights distribution.

Graphical representation of all possible distribution of order weights is shown in figure 5.

Fig. 4: Decision behaviour according to the selected order weight distribution.

3.6.3 IDEAL POINT METHODS (TOPSIS)

Ideal point methods order a set of options on the basis of their separation from the ideal solution. The ideal solution represents an (not achievable and thus only hypothetical) option that consists in the most desirable level of each criterion across the options under consideration. The option that is closest to the ideal point is the best one. The measurement of separation requires distance metrics. The ideal negative solution may be defined in the same way: the best option in this case is characterised by the maximum distance from it. The formulas 13 and 14 show the generalised definition of distance metrics (using weighted Minkowski L_P metrics). For p = 1, the rectangular or *city distance* is calculated. For p = 2 the Euclidian distance is obtained.

$$s_{i+} = \left[\sum_{j=1}^{n} w_j^p \left(u_{ij} - u_{+j} \right)^p \right]^{1/p} \qquad 13.$$

s_{i+} … separation of the i*th* option from the ideal point
w_j … weight assigned to the criterion j
u_{+j} … ideal value for the j*th* criterion
p … power parameter ranking from 1 to ∞

$$s_{i-} = \left[\sum_{j=1}^{n} w_j^p \left(u_{ij} - u_{-j} \right)^p \right]^{1/p} \qquad 14.$$

s_{i-} … separation of the i*th* option from the negative ideal point
u_{-j} … negative ideal value for the j*th* criterion

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is one of the most popular compromise methods. TOPSIS defines the best option as the one that is closest to the ideal option and farthest away from the negative ideal point. The method requires the cardinal form of the performance of options. The distance from the ideal / negative ideal point is calculated as in Formula 15 and 16.

$$s_{i+} = \left[\sum_{j=1}^{n} \left(u_{ij} - u_{+j} \right)^2 \right]^{0,5} \qquad 15.$$

$$s_{i-} = \left[\sum_{j=1}^{n} \left(u_{ij} - u_{-j} \right)^2 \right]^{0,5} \qquad 16.$$

The relative closeness to the ideal solution (c_{i+}), which will be used for the ranking of options, is calculated as in formula 17.

$$c_{i+} = \frac{s_{i-}}{s_{i+} + s_{i-}} \qquad 17.$$

Considering a simple example of two options and three criteria with already weighted performances

	a_1	a_2	ideal positive solution	ideal negative solution
C_1	0.08	0.32	0.32	0.08
C_2	0.2	0.044	0.2	0.044
C_3	0.18	0.05	0.18	0.05

The distances from the positive and negative ideal solutions as well as the final aggregation according to the formula 17 is performed as following:

	a_1	a_2
s_{i+}	0.24	0.20
s_{i-}	0.20	0.24
c_{i+}	0.46	0.54

For example $s_{i+}(a_1)$ = ((0.08 – 0.32)^2 + (0.2 – 0.2)^2 + (0.18 – 0.18)^2)^0.5 = 0.24

$c_{i+}(a_1)$ = 0.20 / (0.20 + 0.24) = 0.46

Since $c_{1+} = 0.46 < 0.54 = c_{2+}$ the option a_2 is preferred - $a_1 \prec a_2$

Example 3: *Aggregation using the TOPSIS decision methods.*

3.6.4 ELECTRE

ELECTRE uses a different approach to decision support than value/utility function approaches. It bases on a pairwise comparison of the alternatives, so it's computationally more demanding. It imposes so-called outranking relation on a set of alternatives. An alternative ***a*** outranks an alternative ***b*** if ***a*** is at least as good as ***b*** and there is no strong argument against. There is a variety of ELECTRE techniques, the **ELECTRE III** was implemented in the mDSS4. Normally the alternatives have cardinal outcomes in all criteria.

Terms:

i …index labelling a criterion

$z_i(a)$ …. Outcome of the alternative ***a*** with regard to the criterion ***i***

Concordance index [**C(a,b)**] expresses the strength of support, given the available evidence, that ***a*** is at least as good as ***b*** considering all criteria

C_i(a,b) – concordance index over alternative ***a*** and ***b*** with regard to the criterion ***i***

Discordance index [**D(a,b)**] measures strength of the evidence against this hypothesis

D_i(a,b) – discordance index over alternative ***a*** and ***b*** with regard to the criterion ***i***

Preference threshold p_i is a parameter for each criterion *i*

Indifference threshold q_i is a parameter for each criterion *i*

$q_i < p_i$

Veto threshold t_i is a parameter for each criterion i

$\mathbf{w_i}$ weight of the criterion ***i***

The parameters p_i, q_i, t_i is given by user as an input. There is no restriction of the value for these parameters, apart of that in row 26.

Algorithms:

(1) The start point is the analysis matrix. The parameters p_i, q_i and t_i have to be defined by the user.

(2) Compute index $C_i(a,b)$ for all pairs of alternatives ***a*** and ***b***

	= 1	if $z_i(a) + q_i(z_i(a)) >= z_i(b)$
	= 0	if $z_i(a) + p_i(z_i(a)) <= z_i(b)$
$C_i(a,b)$	[0, 1] =1- $[(z_i(b) - z_i(a) - q_i(z_i(a))/ (p_i-q_i)]$	if $z_i(a) + q_i(z_i(a)) < z_i(b) < z_i(a) + p_i(z_i(a))$

(3) Aggregate $C_i(a,b)$ to $C(a,b)$

$C(a,b) = \mathrm{Sum}\ (w_i \times C_i\ (a,b)\ )\ /\ \mathrm{Sum}\ (w_i)$

(4) Calculate a discordance index

	= 0	if $z_i(a) + p_i(z_i(a)) >= z_i(b)$
	= 1	if $z_i(a) + t_i(z_i(a)) <= z_i(b)$
$D_i(a,b)$	[0, 1] = $(z_i(b) - z_i(a) - p_i(z_i(a))/ (t_i-p_i)$	if $z_i(a) + p_i(z_i(a)) < z_i(b) < z_i(a) + t_i(z_i(a))$

Please note, if no veto treashold (ti) is specified, than Di(a,b) = 0 for all pairs of alternatives.

(5) Calculate **Credibility index** S(a,b)

	$= C(a,b)$	if $D_i(a,b) <= C(a,b)$ for each ***i***
$S(a,b)$	$C(a,b) \times \Pi((1-D_i(a,b))/ (1-C(a,b)))$	Otherwise; but only for the set of criteria for which $Di(a,b) > C(a,b)$

(6) Determine rank order

Descending distillation

(6.1) Calculate $\lambda max = max\ S(a,b)$

(6.2) $\lambda = \lambda max - (0.3 - 0.15\ \lambda max)$

(6.3) For each alternative ***a*** determine the number of alternatives ***b*** with $S(a,b) > \lambda$

(6.4) For each alternative ***a*** determine number of alternatives ***b***

with $(1- (0.3 - 0.15\lambda)) \times S(a,b) > S(b,a)$

(6.5) For each alternative make the difference between (6.3) and (6.4). The alternatives with largest difference (qualification) is called first distillate (D_1).

(6.6) If D_1 has more alternatives than a single one repeat the process on D_1 until all alternatives were classified. If there is a single alternative, than this is the most preferred one. Then continue with the original set of alternatives minus the set D_1, repeating until all alternatives are classified.

Ascending distillation

The same algorithm but in point 6.5 take the options with lowest difference

Final ranking:

There are several ways how to combine both orders. The most frequent is the intersection: Intersection of two outranking relations aRb (a outranks b according to R) if and only if a outranks or is in the same class as b according to the orders corresponding to both relationships.

See for more detail and an application example in Belton and Stewart (2002).

3.7 SENSITIVITY ANALISIS

Sensitivity analysis (SA) is an important task in multicriteria decision making: it looks at how robust (or weak) the final decision is, in the case that even a slight change in the decision outcomes or previously expressed preferences is made. Sometimes the sensitivity analysis is distinguished from a robustness analysis: while the sensitivity analysis is assumed as the analysis of the effects of changing data and model parameters in a constrained vicinity to a base solution, the robustness analysis is considered as a systematic analysis of a large set of variations which are plausible in the decision problem context.

3.7.1 INTRODUCTION

Sensitivity analysis deals with the investigation of potential changes and errors and their impacts on the results of underlying models. Sensitivity analysis, applied post-hoc to decision models, deals with *uncertainties* related to the decision outcomes and/or to the preferential judgements (i.e. value function and criterion weights). The objective is to find out how the options ranking changes by any modification made on the decision models. While the impact of uncertainties on the decision outcomes is mostly analysed by statistical modelling and simulation, the preferential judgements are object of uncertainty during the modelling of weights and value function. However, SA provides neither a explicit probabilistic measure of the risk to make a wrong decision nor an explicit treatment of the risk attitude of the DM.

Sensitivity analysis may be used for wide range of different uses (for detail see Pannell 1997). The SA methods are useful within (i) decision making for identifying critical value/criterion, testing robustness and riskiness of decision; (ii) communication for increasing credibility and confidence; and (iii) modelling process for better understanding of input-output relationship and for understanding the model needs and restrictions.

Sensitivity analysis approaches differ in the level that they address: (i) approaches targeted to local level consider only the immediate neighbourship of a given starting point (e.g. a previously identified optimal solution of a decision problem); while (ii) the approaches working on a global level vary all input parameters over their range of uncertainty. At the same time one or more parameter may be considered to vary. By a single parameter test all other parameters are held fixed. This is a common approach that is used, although the interactions between two or many parameters are ignored and their combined impact is not analysed. On the other side, multi-parameter tests are computationally very complex and thus less practical.

Performing the sensitivity analysis may be a complex undertaking. Considering just a simple example with 5 options and 5 criteria: the simulation of the criterion weight taking into account only 20 different values for a weight (sampling step 0,05) would encompasses 4151 calculations of overall preference function producing 4151 feasible ranking vectors. Additionally, the search for the feasible weights' combination from all 3.200.000 ones is also considerable.

A suitable SA depends on the decision rules chosen for the preferences aggregation. While the decision rules discussed for implementation in the *m*DSS are mostly based on criteria weights, the main concern of the sensitivity analysis will be oriented to the uncertainty addressing the criterion weights.

The *m*DSS utilises two approaches for SA: (i) most critical criterion: identifying the criterion for which the smallest change of current weight may alter the existing ranking of options; and (ii) tornado diagram: graphically comparing the chosen option with any other one and showing ranges within which the parameters may vary.

3.7.2 MOST CRITICAL CRITERION

This method developed by (Triantaphyllou 2000) considers the most critical criterion to be the one which requires the minimal amount of change in the current value of its weight in order to change the options' rank order. Using this method, the user may directly test if the minimal change in criteria weights which leads to the final rank disturbance is within or outside his confidence range.

The method distinguishes two rank order changes:

- the top critical criterion is that one which changes the best ranked option (T method).
- any critical criterion is that one which changes ranking of any options (A method).

The algorithm to estimate the critical criterion encompasses following steps:

1. List all possible changes in options' rank order caused by modification of criteria weights (e.g. how much must change the weight w_i in order to change the rank order between the first two options). There are only

$$n \times m(m\text{-}1))/2 \qquad 18.$$

changes in rank order possible (with n… number of criteria; and m.. number of options).

In case of three options and two criteria: there are three possible rank order changes which may be caused by changes in two criteria - 2 * 3 * 2 / 2 = **6**

	c_1	c_2
a_2 () a_1	1	2
a_3 () a_1	3	4
a_3 () a_2	5	6

2. For each change of options' rank order calculate the difference of total options' performance

	ΔP
a_2 () a_1	$(P_2 - P_1)$

a_3 () a_1	$(P_3 - P_1)$
a_3 () a_2	$(P_3 - P_2)$

(P_i is obtained as result of decision rule from the choice phase, aggregation result)

3. For each rank change and for each criterion calculate difference between the options' performance.

	c_1	.	c_n
a_2 () a_1	$a_{21} - a_{11}$	.	$a_{2n} - a_{1n}$
a_3 () a_1	$a_{21} - a_{11}$	.	$a_{3n} - a_{1n}$
. . .	. . .	.	…
a_m () a_{m-1}	$a_{m,1} - a_{m-1,1}$	.	$a_{m-1,n} - a_{m,n}$

(a_{ij} is the corresponding value from the evaluation matrix, i.e. standardised and weighted option's score)

4. Calculate a new matrix dividing the cell values of the matrices created in step 2 and 3.

	c_1	.	c_n
a_2 () a_1	$(P_2 - P_1) / (a_{21} - a_{11})$	.	$(P_2 - P_1) / (a_{2n} - a_{1n})$
a_3 () a_1	$(P_3 - P_1) / (a_{21} - a_{11})$	.	$(P_3 - P_1) / (a_{3n} - a_{1n})$
. . .	. . .	.	…
a_m () a_{m-1}	$(P_m - P_{m-1}) / (a_{m,1} - a_{m-1,1})$	.	$(P_m - P_{m-1}) / (a_{m-1,n} - a_{m,n})$

5. Exclude unfeasible weights changes

The unfeasible solution (no changes in weights are able to change the rank order) should be excluded from consideration. The value of the previous matrix are feasible if there are less then the criteria weights ($\mathbf{w_k}$) indicated by user and used for aggregation in the choice phase.

$$(P_j - P_i) / (a_{jk} - a_{ik}) \le w_k \qquad 19.$$

where ***i*** and ***j*** indicate two options (best option ≤ ***i*** < ***j*** ≤ worst solution) and ***k*** indicate a criterion.

6. The remaining feasible solutions represent changes in the corresponding weights in order to reverse the option ranking. The **rows minimal** (absolute) **value** indicates the critical criterion for a given change in rank and the minimal feasible value in the whole matrix indicates the critical criterion for any changes in options' rank order. To obtain the **critical criterion for top rank** changes the minimal value in the first (***m*** – 1) rows is to be found.

	c_1	.	c_n	
A_2 () a_1	*minimal value indicate critical criterion to reverse the rank order between* $a_2 - a_1$			*minimal value indicate critical criterion to reverse the rank order between the best ranked (*a_1*) and any other option*
A_3 () a_1	*minimal value indicate critical criterion to reverse the rank order between* **any options' pair**			
. . .				
a_m () a_{m-1}				

Considering the following decision matrix (left) producing the aggregated options performances as in the column right

	c_1	c_2	c_2	
w_i	0,33	0,33	0,33	P_i
a_1	0.2	1	0.4	0.528
a_2	0.5	0.3	0.4	0.5*0.33 + 0.3*0.33 + 0.4*0.33= 0.396

After applying a SAW aggregation method the option a_1 is preferred. The goal of the SA is to find out, which criterion weights is most sensible for the final ranking and how much is it to be changed in order to reverse the options ranking.

Calculation of the differences in options performances (a_{2i} - a_{1i}) - left; right - calculation of difference in options' performance (ΔP)

	c_1	c_2	c_3	ΔP
a_2 () a_1	0.5 – 0.2 =0.3	0.3 - 1 = - 0.7	0.4 – 0.4 = 0	0.396 - 0.528 = - 0.132

Calculation of the (P2 - P1) / (a2i - a1i)

	c_1	c_2	c_3
a_2 () a_1	- 0,132/0.3 = - 0.44	- 0,132/ - 0.7 = 0.188	∅

Identifying the most critical criterion and the magnitude of the change of its weight

	c_1	c_2	c_3
a_2 () a_1	- 0.44	0.19	∅

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→***Consistency check*** – change of both criteria weights may cause rank reverse because both value above are less then the current criteria weights

→ ***Critical criterion*** = c_2 because |0.188| < |-0.44|

Calculation of new weight w1'

$w_{2'} = 0.33 - (0.19) = 0.14$

Standardisation of new weights (w*)

$$w1^* = w1/(w1'+w2+w3) = 0.33/0.8 = 0.41$$

$$w2^* = w2'/(w1'+w2+w3) = 0.14/0.8 = 0.18$$

$$w3^* = w3/(w1'+w2+w3) = 0.33/0.8 = 0.41$$

Proof: Applying the new weight set the resulting aggregated performances are equal.

	c_1	c_2	C_2	
w_i	0,41	0,18	0,41	P_i
a_1	0.2	1	0.4	0.42
a_2	0.5	0.3	0.4	0.42

Example 4: *Most critical criterion approach for sensitivity analysis applied for the SAW decision rule.*

3.7.3 TORNADO DIAGRAM

The tornado diagram is a graphical method of sensitivity analysis. The advantage of this approach is its visual representation of sensitivity that compares two options (a basic and a challenging one) at a time. The horizontal bars represent the ranges of the options' total performance obtained by the variation of each weight. Bars are arranged from widest to narrowest and thus produce a "tornado" shape.

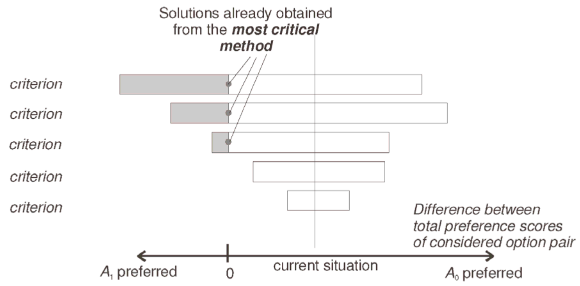

Fig 5: The tornado diagram showing the differences in total performance of two options obtained by varying of criteria weights.

On the x - axis the difference in total performance between compared solution is shown. Notice that the zero points – with equal performance of both options – correspond to the weights obtained from the critical criterion approach.

3.8 GROUP DECISION MAKING - AGGREGATION OF GROUP MEMBERS' PREFERENCES

Decision making which involves two or more decision makers encompasses a variety of techniques, which allow the group to search for solutions and to evaluate them. Decision theory distinguishes two main streams in these cases: (i) group decision making characterised by the common effort of a group of decision makers to resolve a given decision problem; and (ii) game theory, which also handles situations where two or more decision makers (players) face a decision problem, but in this case each player wants his own optimal solution to be accepted.

3.8.1 INTRODUCTION

Group decision making regards a situation in which two or more decision makers are involved in a joint decision whereas each of them has his own perception of the decision problem and the decision consequences. According to (Choi; Suh, and Suh 1994) group decision problems are social problems rather than mathematical ones with only few methodologies to verify their fairness, i.e. the way in which the individual preferences are aggregated. Various attempts have been undertaken to extend MCA techniques to be able to deal with interpersonal conflicts. The different preferences of decision group members create a new "dimension" of a decision problem, which, in order to obtain a common decision model, has to be aggregated in a similar way as the preferences for multiple criteria are dealt with in MCA.

"Behaviour aggregation" is the name for the process by which the group members are able to compromise their expectations and agree on a common system of objectives and preferences. After an communicative phase, the decision makers assume a unified problem structure and common value/utility functions.

If this process fails – i.e. the behaviour of any group member is uncooperative – formal aggregation procedures (voting rules) may be used to select a compromise solution. In this case each decision maker may solve the given decision problem on his own. The individually chosen solutions are then presented and compared to each other through voting. A large decision group may take advantage of this procedure ,but in a small group there is a risk, that one group member (dictator) systematically affects the decision process and thus "dictate" a solution.

3.8.2 COMPROMISING CRITERIA WEIGHTS

If the *m*DSS were to be used in a group decision situation, first the behaviour aggregation approach might be proposed. The decision group members are asked to discuss the problem structure, the main goals and their concrete operative attributes, and the decision preferences expressed through the value functions and criterion weights. If such a co-operative approach is possible and the decision group reaches an agreement, the process would require only an advanced exploration technique for the table and spatial data views. The function of supporting communication within the group does not necessary suppose that all members interact at the same place and time.

Should the problem understanding and the preferences be slightly different, but the group members are principally willing to make a common solution, some procedures that compromise the differences may be implemented. The group members may have different expectations regarding the considered criteria and options, the value/utility function that is used and the importance of criterion (weights). If the differences are small, a mathematical approach or an approach dealing with incomplete information may be chosen. If the differences are not overcome, then a voting rule or an inter-personal preference comparison approach should be chosen.

3.8.3 COMPROMISING THE FINAL SOLUTION

In this case the weights are to different or the group was not able to compromise to find a common value function for all criteria. In order to find a compromise solution, the final ranking is to be taken into consideration. The Borda technique assigns ranks to options based on the rationale that the higher the position of an option on the voter's list, the higher the rank assigned. The voting position of an option is determined by adding the ranks for each option from every voter using the Borda vote aggregation function. The winner is an option that receives the highest score calculated such that all options are assigned a score starting with 0 for the least favourable solution, 1 for the second worst, 2 for the third worst, and so on. All scores are weighted by the number of voters, resulting in the Borda score for each option.

Borda vote aggregation prevents a contentious option that ranks very high with some group members and very low with others from winning, and promotes a consensus option. Low variance scores are indicative of situations where the decision-makers prioritised an option in about the same position in the list in each of their individual lists ("0" indicates exactly the same position for all three). High variance scores are indicative of one decision maker ranking an option higher in a ranked-list relative to another decision maker who might have ranked the same site lower, or in the middle of the list.

3.8.3.1 INDIVIDUAL RANKING

Each decision group member performs the decision analysis on his own (using his own copy of the mDSS). The result of each individual decision is supposed to be a full ranking of all available options.

3.8.3.2 GROUP RANKING – BORDA RULE

Group decision making compromises the individual rank orders of options. Each group member attributes an individual Borda mark to each option. The borda mark shows an option's preferential relationship to other possible options (formula 1). The best option in a individual ranking obtains (***n***-1) value, where ***n*** is number of criteria. Similarly, the worse option in a given ranking is marked with 0.

$\succsim_k$ preference relation of decision maker ***k***

$a_j \succsim_k a_i$ options ***a$_j$*** is preferred by the decision maker ***k*** to option ***a$_j$***

$r(a_j \mid A, \succsim_k)$ .. number of options that decision maker ***k*** ranks at most as good as ***a$_j$*** (number of options which are less ranked as ***a$_j$***)

$$r(a_j \mid A, \succsim_k) = \# a_i \in A \mid a_j \succsim a_i \qquad 20.$$

To determine the consensus ranking, the total Borda mark is calculated according to formula 20. The individual marks are summarised for each option and the best (consensus) option is the one with highest total Borda mark.

A option ***a$_j$*** is preferred another option ***a$_j$*** ($a_j \succsim a_i$) in the final group ranking only if

$$\sum_{k=1}^{m} r(a_j \mid A, \succsim_k) \geq \sum_{k=1}^{m} r(a_i \mid A, \succsim_k) \qquad 21.$$

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Considering a simple example of three decision makers {A,B,C} and three options {a_1, a_2, a_3}

A) Initial individual rankings

	Best options	..	Worst option
Decision maker A	a_1	a_2	a_3
Decision maker B	a_2	a_1	a_3
Decision maker C	a_2	a_3	a_1

B) Individual Borda mark

	Option a_1	a_2	Option a_3
Decision maker A	2	1	0
Decision maker B	1	2	0
Decision maker C	0	2	1

C) Total Borda mark

	Option a_1	a_2	a_3
Total Borda mark	3	5	1

D) Final ranking

Since the highest Borda mark has been assigned to the option a_2 and the second highest to the option a_1, the group ranking is $a_2 \succ a_1 \succ a_3$

Example 5: *Group Ranking – Borda rule.*

3.8.3.3 ALTERNATIVE GROUP RANKING

In the mDSS4 a few alternative group decision algorithms have been implemented. **Condorcet winner** (called after the mathematician and philosopher Marie Jean Antoine Nicolas Caritat, the Marquis de Condorcet) is an option which, when compared individually with each of the alternative options, is preferred by a majority of voters. The Condorcet winner is estimated by a series of imaginary pairwise contests. In each contest, the option wins which is ranked higher than the other one by most voters (decision makers, stakeholders). When all possible pairs of options have been considered, the option which beats every other options in these contests is declared the Condorcet winner. Due to be cyclic collective preferences, there may be no Condorcet winner. In such a case other group decision method need to be applied.

The second algorithm for group decision making added to mDSS4 resembles the OWA rule. Following this methods, a new set of weights is assigned to different rank positions. The weight vectors are assumed to be decreasing with highest weight being assigned to the top position of the option ranks. Depending on the actual values of the weights, several strategies can be distinguished:

Plurality voting: (1,0,0,…,0): All rank positions but the first are given weight 0. The winner is the alternative that is placed at the first position in the orders by the greatest number of experts.

Anti-plurality voting (1,1,1,…,0): All rank positions but the latest are given weight 1. In this method the experts indirectly point out the alternative judged as the worse one. The winner is the alternative that is placed at the last position in the orders by the least number of experts.

Z–plurality method (1,1,….,n-z = 1, 0,0,…0): The first n-z rank positions are assigned the weight 1 (n .. number of options, z…arbitrary chosen number, n>z). It is easy to show that if z=n-1, plurality voting is produced, and if z=1, the corresponding results equal to anti-plurality strategy.

To calculate collective preference, the weights are multiplied with the number of times an option was ranked at a certain position.

4 ANNEX

4.1 CONSISTENCY TEST OF RECIPROCAL MATRIX OF PAIRWISE COMPARISON

The important point is that the expected rank of ***A*** (if ***A*** is consistent) is 1 and the expected *eigenvalue* is equal to number of compared criteria (n). In inconsistent cases the expected maximum eigenvalue is grater than n while the others are close to zero. The *eigenvector* of matrix ***A*** is an estimate of the relative weights of the criteria being compared.

In ideal cases the comparison matrix (***A***) is fully consistent, the rank(***A***) = 1 and λ = ***n*** (***n*** = number of criteria). In this case, the following equation is valid:

$$\boldsymbol{A} \times \boldsymbol{x} = \boldsymbol{n} \times \boldsymbol{x} \text{ (where } \boldsymbol{x} \text{ is the } eigenvector \text{ of } \boldsymbol{A})$$

In the inconsistent' cases (which are more common) the comparison matrix ***A*** may be considered as a perturbation of the previous consistent case. When the entries a_{ij} changes only slightly, then the *eigenvalues* change in a similar fashion. Moreover, the maximum *eigenvalue* (λ_{max}) is slightly grater to n while the remaining (possible) *eigenvalues* are close to zero. Thus in order to find weights, we are looking for the *eigenvector* which corresponds to the maximum *eigenvalue* (λ_{max}).

The consistency index (CI) is calculated as following

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad 22.$$

Then, the consistence ratio (CR) is calculated as the ratio of consistency index and random consistency index (RI). The RI is the random index representing the consistency of a randomly generated pairwise comparison matrix It is derived as an average random consistency index (Table 1) calculated from a sample of 500 of randomly generated matrices based on the AHP scale (Table 2)

$$CR(A) = \frac{CI(A)}{RI(n)} \qquad 23.$$

If CR(A) $\leq$ 0.1, the pairwise comparison matrix is considered to be consistent enough. In the case CR(A) $\geq$ 0.1, the comparison matrix should be improved. The value of RI depends on the number criteria being compared.

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Table 4: Random consistency indices for different number of criteria (n).

5 GLOSSARY

The **DPSIR framework** shows a chain of causes-effects from Driving forces (activities) to Pressures, to changes on the State of environment, to Impacts and Responses. DPSIR is based on the assumption that economic activities and society's behaviour affect environmental quality. The relationships between these phenomena can be complex. DPSIR highlights the connection between the causes of environmental problems, their impacts and the society's response to them, in an integrated way.

- The ***Driving forces*** are represented by natural and social processes which are the underlying causes and origins of pressures on the environment. E.g. agriculture/land use change, industry, waste management. The ***Pressures*** are outcomes of the driving forces, which influence the current environmental state. They are the variables which directly cause (or may cause) environmental problems. E.g. polluting emissions, noise.

- The ***State*** describes physical, chemical or biological phenomena in the given reference area. It reflects the condition of the environment. E.g. air, water, soil quality.

- ***Impacts*** on population, economy, ecosystems describe the ultimate effects of changes of state, in terms of damage caused. E.g. eutrophication, biodiversity loss.

- The ***Responses*** demonstrate the efforts of society (e.g. politicians, decision-makers) to solve the problems. E.g. policy measures.

From the point of view of the decisional context, the Impact describes the existing problem. The negative Impact arises as a change in the environment's State reduces the value (either in quantitative or qualitative terms) of the natural resource. The Response refers to the decision act: the chosen option aimed at reducing the negative pressures on the state of the environment. Driving forces, Pressures and States are the possible levels of intervention: a decision maker can choose one of them (or a combination of them) as a concrete object for his response.

Multi-criteria analysis or multi-criteria decision aid (MCA) is a well known branch of decision theory, sometimes considered as a part of Operational Research, dealing with a number of considered evaluation criteria. Multi-criteria analysis can be used to describe any structured approach to determine overall preferences among alternative options, where the options accomplish several objectives.

A **decision problem** is considered to exist, when a planner or decision maker (DM) perceives a discrepancy between the current and desired states of the planning system, and when (i) the DM has alternative courses of action available; (ii) the choice of action can have a significant effect on this perceived difference; and (iii) DM is motivated to make a decision, but he or she is uncertain a-priori as to which option should be selected.

An **indicator** can be defined as a parameter or value derived from parameters, which provides information about a phenomenon. In particular, an environmental indicator is a parameter, which provides information about the situation or trends in the state of the environment, in human activities that affect or are affected by the environment, or about relationships among such variables.

In Multiple Criteria Analysis, it is an instrument which allows for the synthesis of certain information to lay the foundation for judging an action. This synthesis can be relevant in qualitative or quantitative terms, and relative to particular characteristics, attributes or effects (consequences) which might arise from the action's implementation. Several indicators may be synthesised to define a criterion encompassing a broader point of view.

An **index** is a set of aggregated or weighted parameters or indicators.

Options/possible solutions/ course of actions represent decision acts whose outcomes can be simulated. Possible solutions comprise all feasible actions or activities that solve or contribute to the solution of the decision problem. Relating to the DPSIR framework, they represent the possible responses proposed to address the impacts.

Criterion is a measure against which options are assessed to evaluate the degree to which they achieve objectives. A tool for evaluating and comparing the potential actions according to a well-defined point of view.

Value function is a mathematical representation of human judgements. It translates the performances of the options into value scores, which represent the degree to which a decision objective is matched.

Decision rule is the procedure by which the relative outcomes of available options are aggregated. Through a decision rule the multi-dimensional description of an option's outcomes which refer to a set of decision criteria is transformed into the single value of an overall option's performance.

Evaluation is a process of examining options and assessing their relative performance with regard to the selected criteria. In MCA the evaluation process encompasses both the assessment of the options' outcomes (by means of value function) as well their aggregation by decision rules.

Alternative scenarios are hypothetical future events. They establish the social, environmental and socio-economic settings that can create changes in driving forces, when human activities are involved, and in state, when dealing with the environment. It is an exploration of a possible future for which an underlying set of assumptions has been made.

End user is the person that will use the *m*DSS to examine alternative strategies in water management in the catchment. End users are essentially institutional decision-makers who could use the results of the project in their activity as water managers. To facilitate communication and to avoid misunderstandings, they can be called "DSS users".

Stakeholder is a social actor (individual or collective), who is an actual or a potential user of water resources for different purposes such as agriculture, industry, domestic consumption, recreational, or communication. Stakeholders are affected by the decisions of DSS users.

Integrated assessment (IA) is an interdisciplinary process of combining, interpreting, and communicating knowledge from diverse scientific disciplines in such a way that the whole set of cause-effect interactions of a problem can be viewed from a synoptic perspective (Rotmans and Dowlatabadi, 1998). Integrated assessment implies that science is exemplary and that it is being done in the context of social and economic forces at work in society. It is a new kind of science coupled to new economics, new sociology and new management policies (Harris, 2002).

Integrated assessment and modelling (IAM): is an interdisciplinary and participatory process combining, and interpreting communication knowledge from diverse scientific disciplines to allow a better understanding of complex phenomena (Rotmans and Van Asselt, 1996) The main purpose of IAM should be to inform policy and to support decision making. In some cases, when IAM is difficult or impossible to achieve, the process of IAM rather than the outcome allows important lessons to be learnt. IAM can be a methodology used for gaining insight over environmental problems, a framework to organise disciplinary research, a tool to integrate insights from the natural and social sciences.

IAM seeks to achieve multiple forms of integration in its approach to environmental issues (integration = linking models with GIS, integrating software, integrating stakeholder participation, integrating different scales, disciplines and models).

Today IAM combines the natural and social sciences to provide a broader view of the system and the impediments to better management and sustainability. It also seeks to enhance communication both between researches and stakeholders, and among IAM participants. It is a problem-focused area of research with studies often undertaken on a demand-pull, or stakeholder needs basis.

Tomorrow (optimistically) IAM tools may successfully integrate insights from the natural and social sciences. The results from the modelling and testing of alternate future scenarios are used to depict scenarios that extend beyond the recent range of experience to assist in the evaluation of more extreme events or frequencies and to develop appropriate environment and resource management policies. These results are effectively communicated to politicians, decision-makers, and community partners who then use the findings in their decisions about future actions. The overall pattern is one of integrated modelling, integrated application, integrated communication and integrated decision making (Parker et al., 2002).

Multi-sectoral: the components of a natural and/or social system; a particular resource or segment of the economy.

Integrated water resources management includes the planning and management of water resources and land. This takes account of social, economic and environmental factors and integrates surface water, groundwater and the ecosystems through which they flow.

Task Force Group

Within the NetSyMoD framework, the Task Force Group (TFG) will have the role of overseeing and steering the whole process. The TFG will include insiders – that is, actors directly involved in the process, familiar with it, or with specific expertise of relevance – and outsiders – people who are not familiar with the issue, but who can provide more objectivity, as well as fresh perspectives, mitigating the potential biases emerging from insiders' pre-existing relationship with experts and stakeholders. The usefulness of involving outsiders in the TFG is limited in the case of experts' consultation, and may thus be omitted without the risk of biasing the process. One or more facilitator(s) are then needed to support the TFG, and analyse the outcomes of the brainstorming exercise. The facilitator's role is crucial for providing a correct and effective management of participation, even in these early stages. For the sake of efficiency, it is suggested that the TFG should include between 4 and 8 members.

Brainstorming meeting:

Loosely defined, any group activity involving the pursuit of new ideas can be defined as a brainstorming meeting. Thus, the purpose of a brainstorming meeting is to produce new ideas about a specific topic. A facilitator should be appointed to control the flow of information, and a member of the team to record ideas and report them back to the meetings' participants.

Link to: http://www.scottberkun.com/essays/essay34.htm

Snowball sampling technique:

The snowball technique is used for identifying hidden population such as groups whose organisational capacity is limited and who may not be easily recognisable. The sampling process begins with the TFG identifying the "seeds", a relatively small number of people who are the first to be involved in the process. These seeds are then asked to name other actors belonging, in their view, to the same group of interested parties.

Social Network Analysis:

Social Network Analysis (SNA) is a framework strategy for investigating social structures, which enables researchers to translate core concepts of social and behavioural theories into a formal language, based on relational terms. Wetherell et al., 1994 define SNA in the following way:

"Most broadly, social network analysis (1) conceptualises social structures as a network with ties connecting members and channelling resources, (2) focuses on the characteristics of ties rather than on the characteristics of the individual members, and (3) views communities as 'personal communities', that is, as networks of individual relations that people foster, maintain, and use in the course of their daily lives." (p. 645)

SNA provides procedures to determine how a social system behaves, and mathematical and statistical methods to test the validity of theoretical underlying hypotheses of human behaviour and interactions.

In SNA, actors can be individuals, groups, corporations, etc., who are interdependent. Relational ties establish a linkage between pairs of actors: relations may, for instance, express the evaluation of actors with respect to one another, or they may quantify transfer of resources between actors; there may be behavioural interactions between actors, or physical connections. Relations may be directed (e.g. actor A phones to actor B) or undirected/reciprocal (the existence of a specific relation between actor A and B implies the same relations between B and A). Ties may either be present or absent, or they may have different strengths/values associated with them, etc. Actors and relations together form networks: networks, therefore, are the results of a process of defining a group of actors on which ties are to be measured.

Questionnaire:

Questionnaires should be used when the respondents can answer the questions directly, or when the respondent is a representative of an entity. In addition, questionnaires can also be used to structure face-to-face or telephone interviews. Within the NetSyMoD framework, questionnaires administered either through face-to-face interviews or mail surveys are suggested.

Within the proposed framework, the questionnaire should include at least three sections:

1. Stakeholders' identification.
2. Stakeholders' relations.
3. Stakeholders' views of the problem.

Stakeholders' identification: key attributes of the person interviewed should be recorded in this section, including affiliation and role.

Stakeholders' relations.

The interviewees will be asked to (i) identify the actors whom they interact with; and (ii) to identify the type of relationships existing with each of the actors mentioned previously, as well as the frequency.

Stakeholders' views of the problem.

Information on stakeholders' understanding of the specific decision-making problem, as well as their preferences. Part 3 of the questionnaire is clearly highly specific to the problem being analysed, and it should be structured with open-ended or semi-structured questions. However, it should include information regarding both the problems, and the preferred management responses.

Interviews

Telephone or face-to-face interviews are often used to gather data on egocentric networks. With this technique, there is a need to identify the right line of questioning, and minimise interviewer bias by providing a standard checklist that should be followed. Open-ended questions should be preferred, as they will provide more information (although at the cost of increased difficulty in codifying the data, and comparing across actors).

Key actors

Through a positional analysis, key actors will be identified. Actors are structurally equivalent if they have identical ties to and from all other actors, and on all types of relations – structurally equivalent actors are, therefore, substitutable and, if two or more actors are structurally equivalent, there is no loss in generality in aggregating them. For the purpose of NetSyMoD, positional analysis should be carried out both on the basis of relations and views of the problem. A “similarity threshold” needs to be established, which will determine the degree of similarity required for actors to be considered substitutable.

Power structure

The distribution of power determines the synergies and interactions emerging in the network. The researcher – or the policy maker – will assess the strength and direction of identified relations, and single out those actors who are in a “central” position in the network – that is, those who play a crucial role, and to whose opinion/position the researcher/decision maker needs to pay particular attention to.

Central:

Traditionally, centrality measures of actors have been considered as good proxies for power position, based Freeman’s measures (Freeman, 1979):

- Degree centrality is the number of direct ties that involve a given node; it represents the level of communication activity – or the ability to communicate directly with others

- Closeness centrality depends on the minimal length of an indirect path between non-adjacent nodes, and represents independence – or the ability to reach a large numbers of alters while being able to rely on a minimum number of intermediaries

- Betweenness centrality reflects the intermediary location of a node along indirect relationships linking other nodes. A node with high betweenness has the capacity to facilitate or limit interactions between the nodes that it links. This measure represents control over communication – or the ability to restrict communication of others.

Role

The concept of role explores the behaviour expected of a person occupying a particular social position.

Position

The position occupied by individual actors within the network is intended as the space in the network defined by the way in which occupants of a certain position relate to actors in other positions. Thus, the concept of social position refers to a collection of actors embedded in similar ways in the network.

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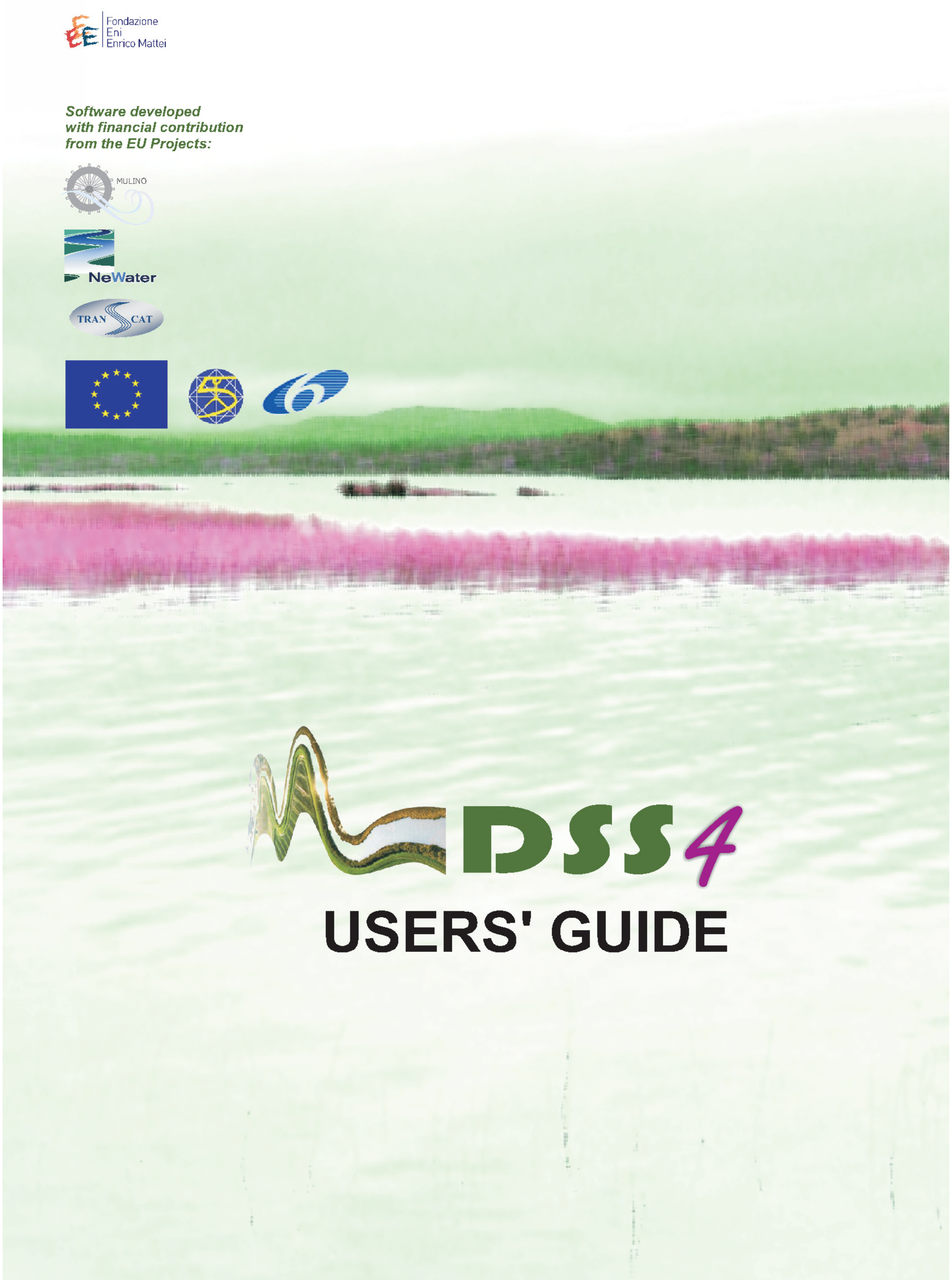
4.8 MDSS4 USER GUIDE

mDSS User Guide. Carlo Giupponi, Jaroslav Mysiak y Jacobo Feás

http://www.netsymod.eu/mdss/decmeth.pdf


Fondazione
Eni
Enrico Mattei
Software developed
with financial contribution
from the EU Projects:
MULINO
NeWater
TRANSCAT
DSS4
USERS' GUIDE

Document information

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This document explains the functional design of the mDSS4, a generic decision support system developed to assist the implementation of the Water Framework Directive and the development of the River Basin Plans. The multicriterio decision analysis (MCA) methods implemented in the mDSS4 are described in details and some examples are used to show how different methods work.

The software and further resources to which this document makes reference are available from: http://www.feem.it/mulino and http://www.netsymod.eu.

This document was written for the mDSS version 4.1, released in October 2006. Further information about the software can be found in “Users’ guide “ and in the practical tutorial “mDSS Tutorial”.

CONTENT

1. INTRODUCTION AND APPLICATION CONTEXT

What is mDSS4

The mDSS was originally developed in the context of the project MULINO (MULti-sectoral, INtegrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale) and further developed and applied with a contribution of several other projects, including DSS-GUIDE, TRANSCAT, NOSTRUM-DSS, NEWATER and BRAHMATWIN.

The mDSS4 is a generic DSS developed to assist water authorities in the management of water resources. It can help you

– to better understand or explain (to stakeholders) the problem at hand,

– to facilitate public participation required by the WFD,

– to take the edge of the conflict related to alternative water uses,

– to extend collaboration with and within different stakeholder groups

mDSS4 integrates models (e.g. hydrological, ecological, socio-economic) with multi-criteria decision methods. The DPSIR framework helps to organise possible cause-effect relationships. Driving forces stand for processes underlying to environmental degradation such as land use or demographic development. Pressure indicators are variables which measures the level of environmental impairment (e.g. total quantity of nitrogen in chemical or biological fertilisers applied per unit of agricultural land). State indicators represent the current condition (or change) of the environment (e.g. average concentration of nitrogen in surface or ground waters). Impacts represent the ultimate effect of changes of State indicators, or the damage caused (e.g. eutrophication of surface water or water becoming unsuitable for drinking). Responses are the policies and measures to solve the problems. They are represented by a set of alternative options to choose from (e.g. alternative plans for ecologically sound production systems, or alternative designs for a water treatment plant).

mDSS4 session is consist of three phases described below:

I) CONCEPTUAL PHASE: identification of the issues and problem exploration.

The DPSIR approach allows the user to conceptualise and structure the decision situation according to the cause-effect relationships, which describe the inherent environmental problem(s) from the perspective of the decision maker (DM). In the real world, after having detected a negative Impact which falls within their competences, DMs investigate the possible causes to identify possible actions: i.e. they proceed backwards from Impacts up to the identification of the most likely Driving Forces. This process leads the DM to the formalisation of DPS chains, which provide a conceptual description of issues, relations and problems upon which future decisions could be based. This phase represents the start of the decision process, usually followed by the identification of suitable model(s) and the analysis of data in the context of the specific decision. The information collected is then organised in the form of indicators in tabular or geographical formats allocated to nodes of the DPS chains.

II) DESIGN PHASE: option definition and modelling

In the second phase, the possible options - responses in terms of the DPSIR framework - are defined and the criteria useful for the evaluation of their performance are identified, on the basis of the available indicators. Hydrological models can implemented in mDSS through a generic interface, which supports a coherent management of Drivers, Pressure and State indicators as distributed (in space and time) catchment variables. Those variables relevant for decision making, either coming from model outcomes or from other sources, are organised in the form of a matrix - the Analysis Matrix (AM) - containing the indicator values of the alternative options for each decision criterion. At this stage the indicator values are measured in different units and scales. In the next phase, indicator values are made comparable by normalisation and/or the application of value functions and used to fill the Evaluation Matrix (EM).

III) CHOICE PHASE: Multi-criteria decision analysis

The comparison of the alternative options is the final phase of the decision making process adopted by mDSS. Using Multi-Criteria Analysis (MCA) evaluation techniques, all options are judged, against their contributions to solve the observed impacts expressed through the criterion values stored in the EM. The main aim of MCA is to reduce the "multidimensionality" of decision problems - the multivariate option performances - into a single measure enabling an effective ranking. The heart of any MCA decision rule is therefore an aggregation procedure. Decision rules aggregate partial preferences describing individual criteria into a global preference and rank the alternatives. There is no single method universally suitable for any kind of decision problem; mDSS provides four decision rules: (i) Simple Additive Weighting (SAW); (ii) Order Weighting Average (OWA), (iii) the Technique for Order Preference by Similarity to Ideal, and (iv) ELECTRE.

What is new in the version 4.1

The version 4 has been developed in the Visual Basic.NET development environment. This has allowed to turn the user interface into a style known from the Windows XP operation system. The functionality of the software changed too, the main changes include:

– a new file format (mDSS4 data file) which is similar as in the mDSS3.x a text base file containing all relevant information regarding the project

– new decision algorithms have been added for aggregating the individual preferences (ELECTRE) and for group decision making

– mDSS4 is one-way OpenMI compliant

– link to the Transcat DSS (and especially its map server component) have been added.

– the DPSIR scheme has been better integrated with other features of the software, allowing to control the application progress

Hardware and software requirements

The mDSS4 requires operation system Windows XP, Me or 2000. Before installing the software, make sure the.NET framework 2005 is correctly installed. The installation file is included in the cd and available form the mDSS web site.

Some software components are installed with the mDSS4 software. The correct functioning of the mDSS4 software depends on the proper installation of these components.

At least 20 MB fee disk space

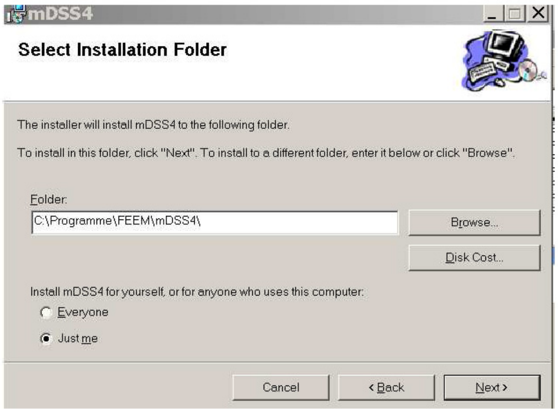
At least 128 MB operational memory (RAM)

2. SHORT INSTALLATION GUIDE

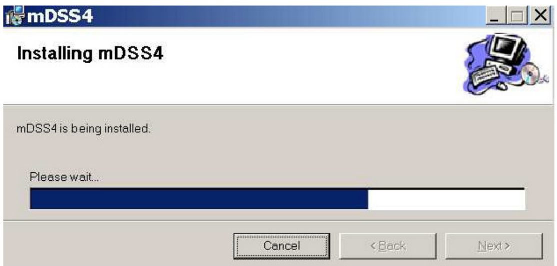
To start the installation, click on the Setup.exe file. If you have not installed the.NET Framework, you will be asked to install it before proceeding with the installation.

If a previous version of mDSS4 is installed on your computer, you must de-install it first. The installation software will detect the existence of an earlier version of mDSS4 on your computer and ask you to remove it (in the language of your operation system).

Click on "Setup" to start the installation.



Select the folder where you want to install the software and click on "Next".



The progress bar shows you the progress of installation. Click "OK" when the installation routine finishes.

3. THE MAIN COMPONENTS OF mDSS WINDOWS

mDSS4 can be started by clicking on the "mDSS" icon in the MULINO DSS program directory.

The main elements of mDSS4 are explained in the figure below.

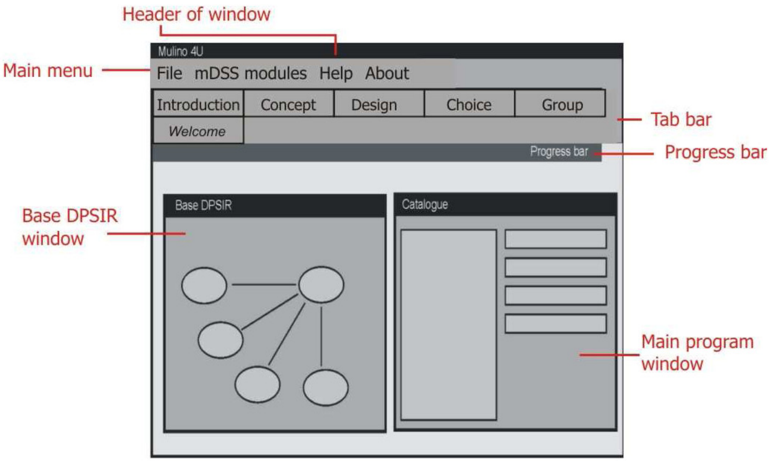


Figure 1.1. Structure of the mDSS user interface

Main menu

The Main menu provides access to the commands which are available for all program frames (such as "Open project"). The item **File** contains options for starting a new project, and opening/saving an existing one. The project files from an earlier version 3.x must be imported before they can be accessed.

Tab Bar

The Tab bar allows to navigate within a project session. It consists of tabs which describe different project phases (Introduction, Concept Phase, Design Phase, Choice Phase, Group Decision). Each phase (directory) encompasses one or more items (subdirectories) allowing to access different program frames. The **progress bar** shows the progress of the current session, the viola part describes already completed part of the process.

DPSIR Window

The DPSIR window can be accessed by clicking on the concept tab. It introduces the Driving force-Pressure-State-Impact-Response framework. The framework guides conceptualisation of the problem at hand. The experiences gained by using the earlier versions of the software confirmed the potential of the DPSIR approach.

Programme Frame

A programme frame contains controls specific for the corresponding progress of the project. The program frames describe the steps underlying a project phase and correspond to the items of a tab bar directory. In some cases multiple windows are opened to allow more effective interaction with the software and to expand the display capability.

NOTE: It is strongly recommended that the user adopts the same strategy during the implementation of a new case study: saving intermediate steps is very useful for implementing subsequent iterations and as an “undo”, in case of problems.

4. INTRODUCTION AND APPLICATION CONTEXT

4.1 Welcome window

Welcome window is the first program frame which appears when the software is started (Figure 4.1). It contains, besides acknowledgements and a short introduction of the NetSyMod approach, two buttons that allow the user to create a New Project or to open an existing one (Open Existing). This functionality is also available in the File command on the main menu.

Note: To access a project file created by an earlier version of mDSS you will need to import this file first, using the Import command form the main menu (File).

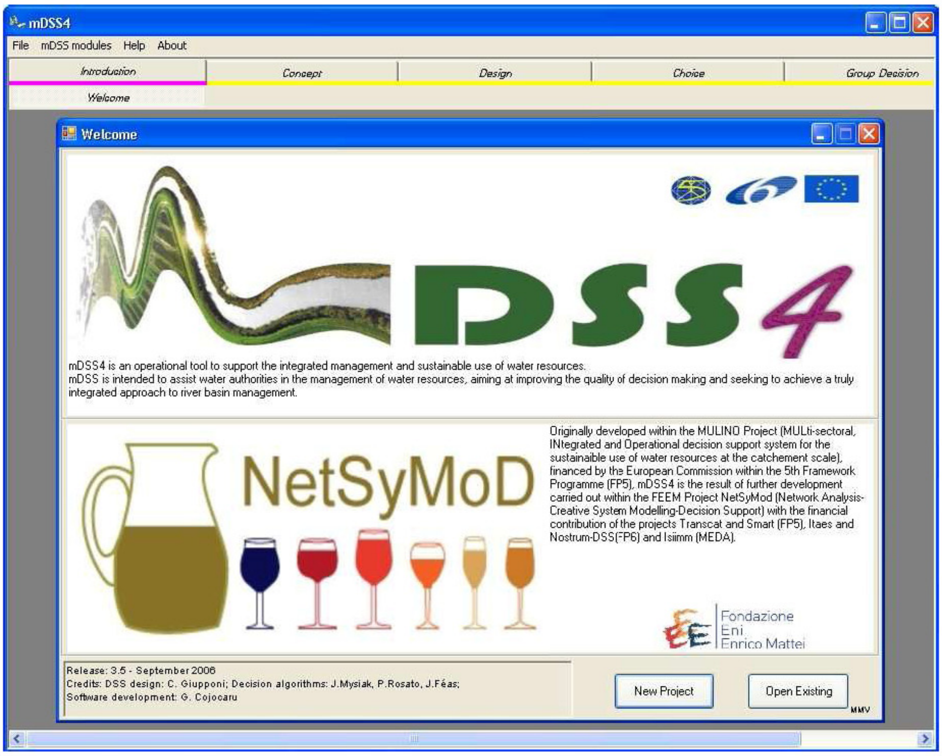


Figure 4.1. Welcome Window (slide 23)

5. CONCEPTUALISATION OF THE PROBLEM

NOTE: If the decision context is well structured, i.e. the decisional criteria and policies are known defined, the decision maker could skip this phase and continue with the following Design Phase (Chapter 6). This may be the case when a similar problem has already been addressed in the past.

5.1 The DPSIR window

When you click on the tab page "Concept" (from the tab bar), the DPSIR window appears (figure 5.1). The main elements of the framework are implemented as buttons. By clicking on the DPSIR buttons the user can move buttons, arrows and indicator list in the screen, to have the best view of the concept phase. By double clicking on them, Catalogue of indicators will appear. Further options are available from context menu which can be opened by clicking on the right mouse button.

The indicators are linked to the four category of DPSI chain; double clicking on single indicator provides the user to have information about the indicator and about the current catalogue. In the same way clicking on single response provide to have information about the response and the catalogue.

Having defined the decisional case and the list of alternative options, the user selects those indicators that are relevant decisional criteria to build the decision matrices. Pressing the "Send *'the indicator'* to Am" button transfers the selected indicators to the Analysis Matrix, thus allowing the user to start the building of the matrix structure by identifying those indicators that will be used later to derive decision criteria. By clicking the right button of the mouse when an indicator is selected the user is provided to read the details of indicator, to add and remove link between indicators, to set value (figure 5.2) and to send the indicator to the Analysis Matrix, that will be defined in the next phase (Design).

mDSS4 USERS' Guide - 5. CONCEPTUALISATION OF THE PROBLEM

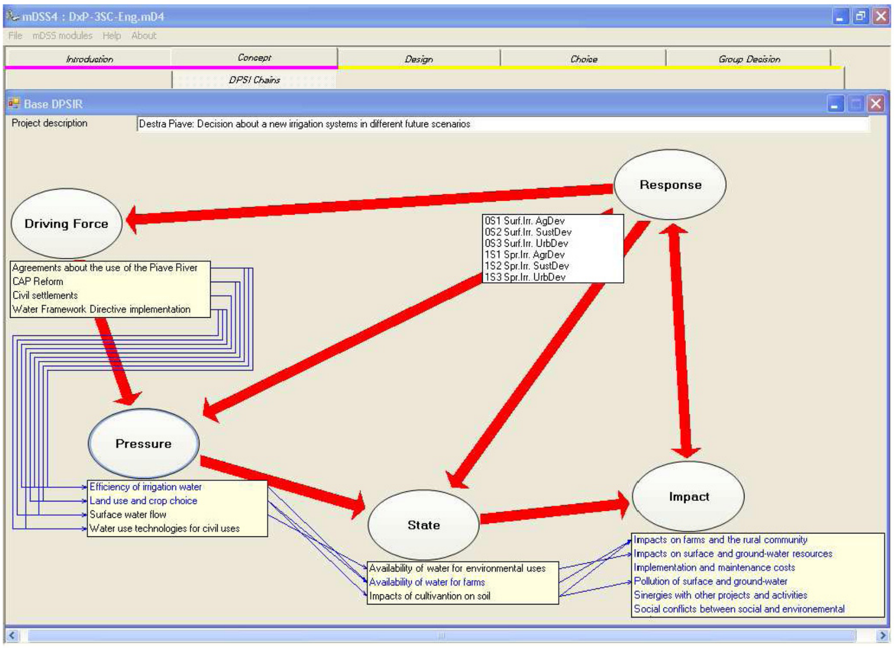


Figure 5.1 Base DPSIR window (slide 25)

11

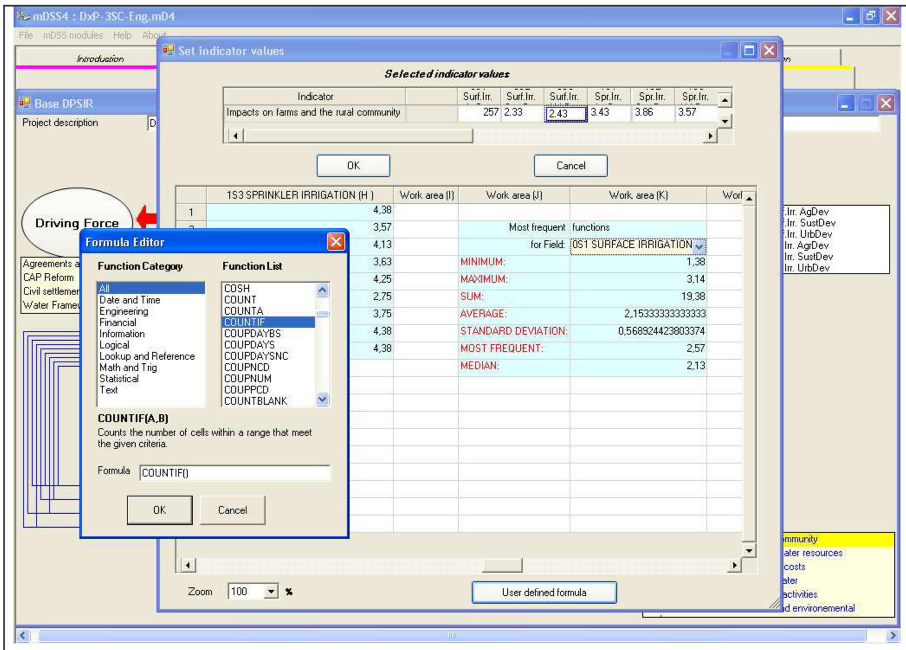


Figure 5.2 Set value from external data base (slide 30)

5.2 The indicators window

Double clicking on the DPSI buttons provides the user to open the Indicators window (see Figure 5.3. The Indicators window is targeted to identify lists of indicators which are relevant for assessing the issue and decision, which is the object of the working session.

The indicators can be grouped in different Catalogue; Catalogues can be external and internal. External catalogues are not referred to a specific project; within the external catalogue indicators can be chosen to identify a list that is used in the single project. The list of chosen indicators represents the Internal Catalogue.

The three buttons below the Catalogue list provide the user to create a new catalogue, to open an existing catalogue or to save the current catalogue. To create a New Catalogue the user is asked to click More button on the right side of the window and mark the External Catalogue option

On the right side of Indicators Window the item description is showed. For each indicator can be defined the sector (the macro area linked to the indicator i.e. agriculture, urban land use and so on) a brief description, the measurement unit, the most frequent role in the DPSI chain, the link with one of the three different dimension of sustainable development (Social, Environmental Economical), the catalogue of provenience, some user comments and the possible source. The consistency range is referred to the interval of values that can be correct for a certain indicator.

By clicking on "more" button the user can analyse the list of indicator using logical functionality ("and" "or"), including or not the selected indicator.

NOTE: The identification of D-P-S-I indicators does not imply any selection of databases or data. It serves instead to formalise the theoretical data needs for a comprehensive description of the human-environmental interactions relevant for the assessment of the problems related to the decisional case in the catchment. Only during the following Design Phase data are stored in databases or maps formally linked to the mDSS project.

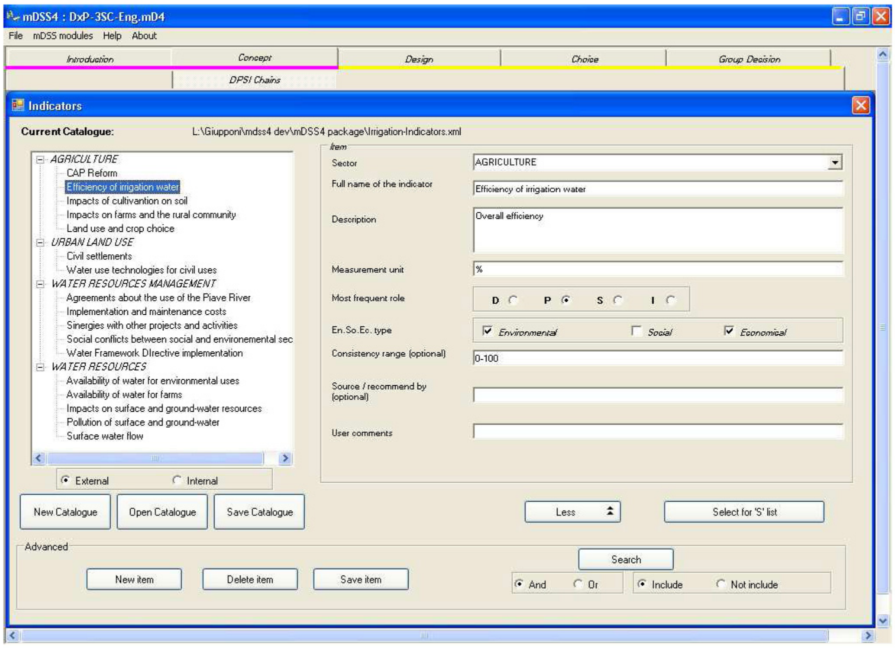


Figure 5.3Indicators window (slide 24)

5.3 The Catalogue of Options window

Double clicking on Response button provides the user to open the Catalogue of Options window (Figure 5.4). Alternative measures can be grouped in catalogue. The Catalogue of Options Window is structured similarly to the Indicator Window. For each response are defined the code, the full name, the target, the category, the actors involved, a brief description and the source.

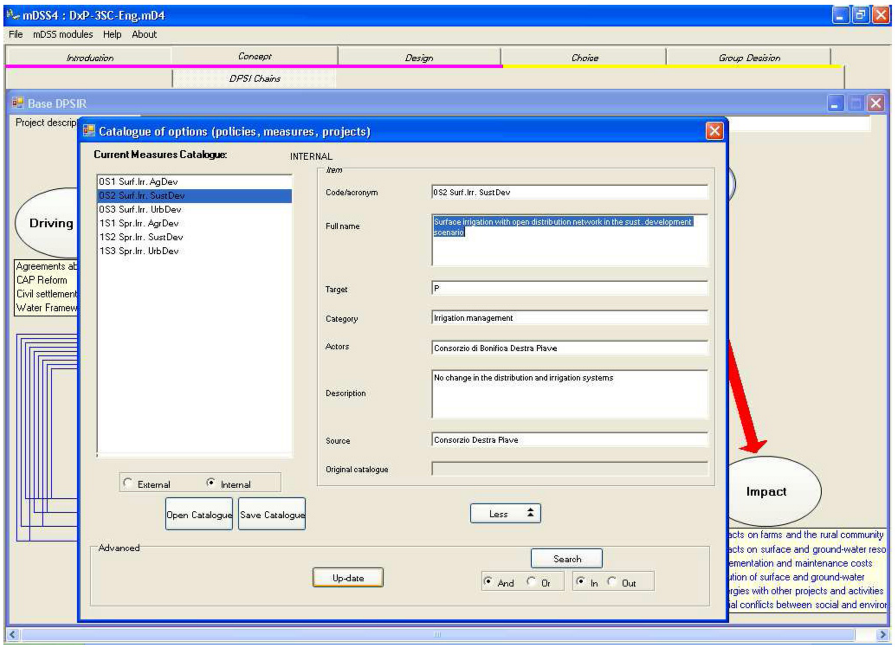


Figure 5.4. Catalogue of Options Windows (slide 27)

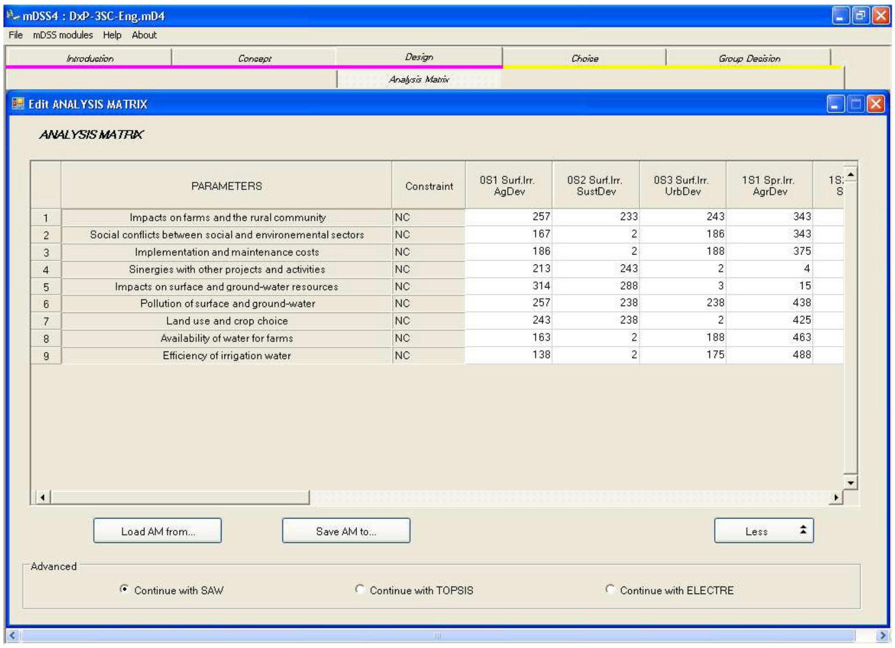
6. DESIGN OF DECISION PROBLEM

In the second phase, the possible options - responses in terms of the DPSIR framework - are defined and the criteria useful for the evaluation of their performance are identified, on the basis of the available indicators. Hydrological models can be implemented in mDSS through a generic interface, which supports a coherent management of Drivers, Pressure and State indicators as distributed (in space and time) catchment variables. Those variables relevant for decision making, either coming from model outcomes or from other sources, are organised in the form of a matrix - the Analysis Matrix (AM) - containing the indicator values of the alternative options for each decision criterion. At this stage the indicator values are measured in different units and scales. In the next phase, indicator values are made comparable by normalisation and/or the application of value functions and used to fill the Evaluation Matrix (EM).

6.1 The Analysis matrix

Clicking on the Design button of the Tab Bar the Analysis Matrix Window appears on the screen (see figure 6.1).

As the name suggests, this program frame encompasses all activities leading to building and filling the Analysis Matrix. The Analysis Matrix (AM) is a tabular representation of decision outcomes measured in natural units (such as kg/yr, m^3, ppm etc.), which are commonly not directly comparable.



	PARAMETERS	Constraint	0S1 Surf.Irr. AgDev	0S2 Surf.Irr. SustDev	0S3 Surf.Irr. UrbDev	1S1 Spr.Irr. AgrDev
1	Impacts on farms and the rural community	NC	257	233	243	343
2	Social conflicts between social and environemental sectors	NC	167	2	186	343
3	Implementation and maintenance costs	NC	186	2	188	375
4	Sinergies with other projects and activities	NC	213	243	2	4
5	Impacts on surface and ground-water resources	NC	314	288	3	15
6	Pollution of surface and ground-water	NC	257	238	238	438
7	Land use and crop choice	NC	243	238	2	425
8	Availability of water for farms	NC	163	2	188	463
9	Efficiency of irrigation water	NC	138	2	175	488

Figure 6.1. Analysis Matrix Window (slide 31)

On the left of analysis matrix window the relevant indicators are showed. Clicking with the left mouse button on indicators provide the user to select the indicator, while clicking the right mouse button after selection provides to remove the item from AM and to set values from other files, e.g. raster or vector files.

On the right side of the AM Window the responses are listed. The numbers inside the matrix represented the indicator values of the alternative options for each decision criterion, and are measured in different units and scales.

Once the structure of the AM has been defined, the cells of the matrix should be filled with indicator values. This phase is not necessary if the AM is loaded from a dbf file already containing all the indicator values.

It is possible to load AM from others project and to save the current AM by clicking on the two buttons on the bottom of the window. Clicking on More button provides the user to continue aggregation in the next phase (Choice) by choosing three kind of algorithm, SAW, TOPSIS and Electre.

NOTE: In mDSS the cells of the AM can be filled in various ways: (i) by loading a pre-existing matrix stored as a dbf file, by pressing the Load AM from.dbf button; (ii) by typing the values manually; (iii) by means of pairwise comparison; (iv) by selecting single values stored in external files; (v) by selecting entire rows from tabular files.

Pairwise comparison (accessible by clicking on the Set Value From button) is the method suggested when no links to external data have been previously identified for the selected D, P, or S indicator. This option is the preferred method for filling the AM from expert judgement. Experts express relative judgements by comparing each option listed in the rows with every other option in the columns and to describe the expected relative performance for the indicator under examination (reported in the upper left corner of the matrix). The choice is made by selecting the best item within a list of levels in accordance with the scale proposed by Saaty between 1/9 (i.e. extremely worse/lower) and 9 (i.e. extremely better/higher) (see mDSS Decision Methods document for details). The result is a list of normalised quantitative values to be copied to the corresponding row of the AM. A Consistency index measures the consistency of the relative judgements in the pairwise comparison matrix.

The selection of Set Values From (spatial or non-spatial data bases) allows the user to set links between AM cells and external files; six categories of data are envisaged as sources for AM indicators:

– Spatial data stored in maps with vector format;
– Spatial data stored in maps with raster format;
– Time series stored in data bases with dbf format;
– Global indicators, i.e. single values expressing the performance of a given option for a certain indicator; global here is intended also as an indicator without spatial features;
– Pairwise comparison of options

– Hierarchical pairwise comparison of options (see above).

Global indicators are stored in a specific ASCII txt data format. In this case the operation is simplest, because global files are simply lists of indicator names with values, separated by "=". Therefore the user should simply select the correct value which is then sent to the AM

NOTE: A global file may be useful when lists of indicator values attached to every option are already available, e.g. in the case of sets of outputs of a certain model or a data processing procedure.

mDSS supports spatial data in ESRI Shape data format for vector maps and ESRI ASCII data format for raster layers. Time series should be stored in dbf format, with indicators on the columns and temporal observations along the rows. Spatio-temporal data usually require pre-processing to extract indicators expressed by a single value. A specific program window has been designed for that scope (see Figure 7.4), which is automatically launched by mDSS whenever spatial or time series indicators are selected.

7. CHOICE

The comparison of the alternative options is the final phase of the decision making process adopted by mDSS. Using Multi-Criteria Analysis (MCA) evaluation techniques, all options are judged, against their contributions to solve the observed impacts expressed through the criterion values stored in the EM. The main aim of MCA is to reduce the "multidimensionality" of decision problems - the multivariate option performances - into a single measure enabling an effective ranking. The heart of any MCA decision rule is therefore an aggregation procedure. Decision rules aggregate partial preferences describing individual criteria into a global preference and rank the alternatives. There is no single method universally suitable for any kind of decision problem; mDSS provides four decision rules: (i) Simple Additive Weighting (SAW); (ii) Order Weighting Average (OWA), (iii) the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and ELECTRE (iv)

7.1 Normalising the values: the value function window

The value function window can be opened by clicking on the choice button of Tab Bar. During this work session the user can processes the Analysis Matrix (AM) to produce the Evaluation Matrix (EM).

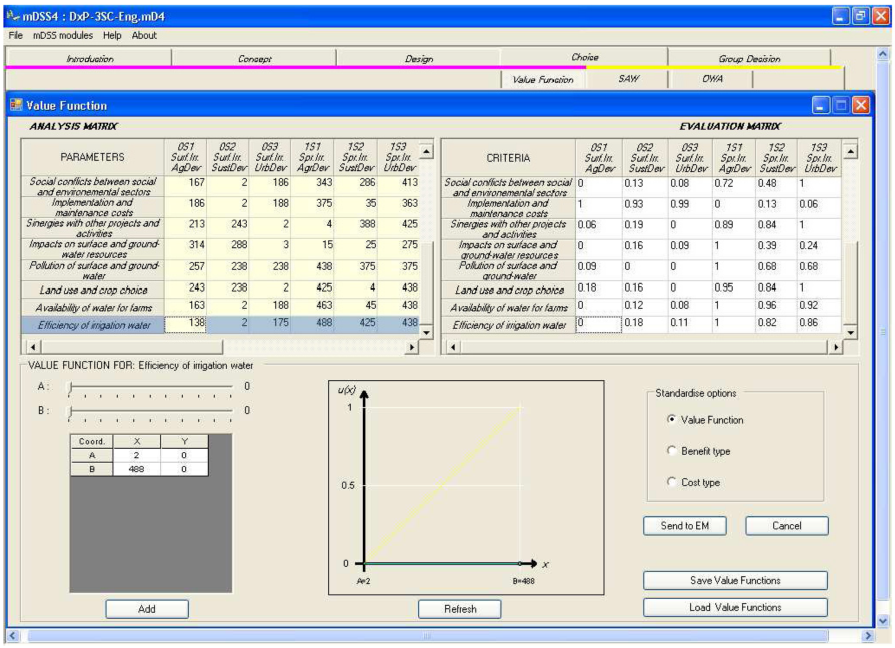


Figure 7.1. Value Function window (slide 32)

The Value Function Window (Figure 7.1) contains both the analysis and evaluation matrices. Initially, the evaluation matrix window, on the right of the window, is empty and the user must individually select every row of the AM and press the Send to EM button to build the EM. At the end of this process the EM contains the normalised values of the analysis matrix - the values in each row of the analysis matrix transformed to a common [0, 1] range.

Both the Analysis Matrix and the Evaluation Matrix can be edited by clicking on the table to modify dimensions of rows and columns.

The transformation of the multidimensional indicators stored in the Analysis Matrix into evaluation indices to fill the Evaluation Matrix is a crucial step in which the decision maker judges the performances of the alternative options measured or estimated in the AM in terms of preference with respect to the specific decisional case under examination. By working on the "Value function" the user transforms the AM data (expressed in natural units) by using the value function approach. The implemented routine allows the user to construct a range of different linear value functions as described below.

NOTE: Three alternative forms of value function (Standardise options) are available for transforming the indicator values expressed in natural units (m3/d, t, etc.) into 0-1 normalised and thus comparable evaluation criteria:

By clicking on "Value function" the user can create a range of different piecewise-linear value functions as shown in Figure 7.1. The parameters of the value function (Y0, Yn) define the first and last point of the modelled value function. By clicking on the pale blue line in the graphic, the user adds new points that define the value curve. The co-ordinates of those points are reported in the table on the left. Editing of the value curve is ended with a double click. The curve can be edited also by clicking on Add Button and inserting manually the coordinates.

By clicking on "Benefit type)" the user is allowed to transform the AM data (expressed in natural units) through a min-max normalisation by applying a linear transformation to the data stored in the chosen AM row, in which a zero value is given to the minimum value of the row, while 1 is given to the maximum;

By clicking on "Cost type)" the min-max normalisation is applied with reversed scale, in which a zero value is given to the maximum value of the row, while 1 is given to the minimum ;

On the left side of the screen the user can find two rulers ,A and B, that provide to move the coordinates of the two points on y axis.

7.2 Assigning weights

Once the Evaluation Matrix is filled the user can pass to the assigning weights work session. Through criteria weighting the decision maker expresses the relative relevance of each decisional criterion stored in the EM for the decision to be taken. The weighting procedure produces a vector of weights which may be saved by means of the "Save the weights " button in a separate file (see Annex: Files description) and reloaded in subsequent working sessions with the "Load the weights" button. These functions are useful in particular for group decision making. After this step, aggregating the decision outcomes according to the decision-maker's preference can be undertaken.

The path of the methodology changes in function of the decision rule chosen before.

7.3 Defining criterion weights

The criterion weights may be defined in four ways:

1- They may be defined independently (option "Independent" should be active in the weight quadrant) by moving the sliders and then normalised by pressing the "Normalise" button so that their sum equals one; the resulting vector of weights may then be saved in a wgt file for further elaboration.

2- They may be defined in a dependent way (option "Dependent" should be active), in which the changes of one weight are interactively connected to the changes of all the other weights, proportionally to their value.

3- They may be defined by using the Pairwise Comparison Weighting approach (see "P.C.W." button). In the pairwise comparison approach the user is asked to compare each criteria pair individually. For each pair he should indicate how important the criterion in the row is versus the criterion in column. Figure 7.2 below presents an example in which the criterion "Urban settlements " is extremely more important than the criterion "Impermeable developed areas" for the decision to be taken. After having compiled the comparison matrix the associated criteria weights are calculated and appear in the first column of the display. Since the process may generate inconsistencies in the pairwise comparison, the consistency index (see mDSS Reference guide), which appears at the bottom of the display, acts as a guide. If the value of the index is lower than 0.1, the matrix is considered consistent enough. Otherwise the user should revise the comparisons. If the matrix is consistent, clicking on the "OK" button copies the calculated weights into the weight quadrant (sliders) where they may still be interactively changed and their effect visually examined and then saved in a wgt file for further elaboration.

4- They may be defined by using the Hierarchical Weighting approach, in which weights are assigned by comparing subsets of criteria, which are then grouped into macro-criteria at various possible levels of hierarchy. The pairwise comparison approach is also used in this case, but with the advantage of being applied to smaller subsets of criteria. This facilitates comparisons because criteria within a subset are usually more homogeneous and thus more easily comparable (e.g. various forms of pollution). At higher hierarchical levels macro-criteria are compared to each other in new matrices. The higher the hierarchical level, the lower is usually the technical content of the comparison and the higher is the political meaning (e.g. deciding the relative weight of pollution as compared to unemployment). The results of aggregations are stored in EM's of higher level, to be used for further aggregation until a final set of weights is calculated, having selected all the available criteria to build a single macro-criterion which is then equivalent to the goal of the decision. To start Hierarchical weighting the user clicks on Start Select button, then the criterions selected turn in pink. When the aggregation is thought to be finished is requested to click on End Select button, to type the name of new macrocriterion and to assign the weights to the criterions chosen. At every hierarchical level, criteria previously selected are highlighted in yellow and no longer available for hierarchical aggregation. At the end of the hierarchical process, by clicking on the "OK" button on menu the calculated weights are copied into the weight quadrant (sliders) where they may still be interactively changed and their effect visually examined and then saved in a wgt file for further elaboration.

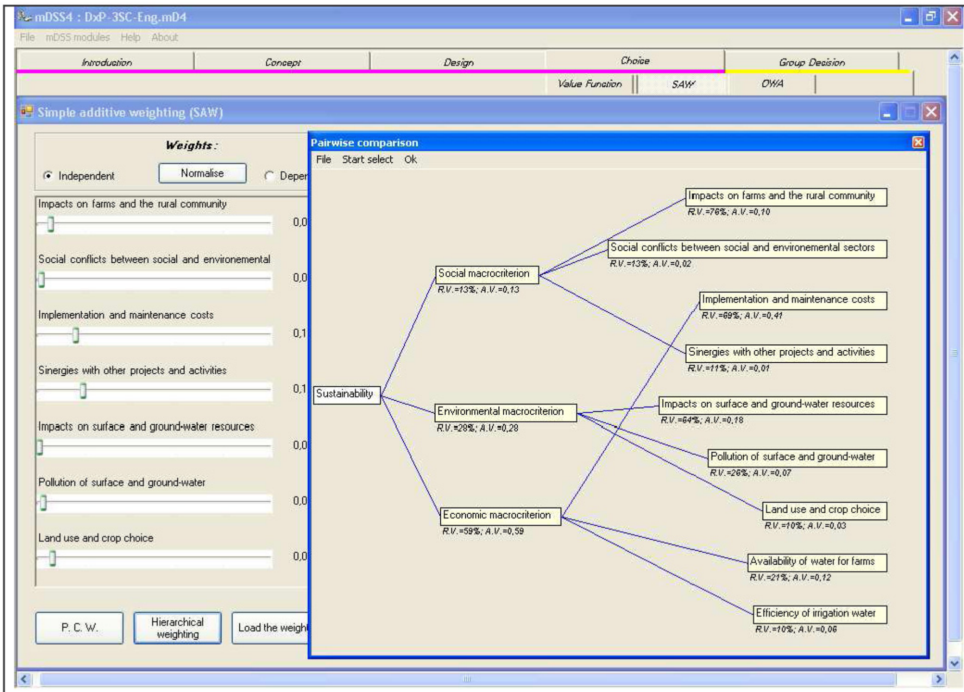


Figure 7.2 Pairwise comparison (slide 33)

7.4 Simple additive weightening

If the algorithm chosen is SAW, then on the screen is showed the following window (Fig.7.3). By clicking on SAW on the Tab Bar the SAW Window appears. SAW is a simple sum of the criterion values of every option, weighted by the vector of weights. The results are expressed by means of scores: the option with the highest score should be preferred.

Once that the vector of criterions weight is defined on the right side of the SAW window appears. the Response for SAW. The best option is coloured in yellow and has a score of 100%. The others are ranked in % relative to first position.

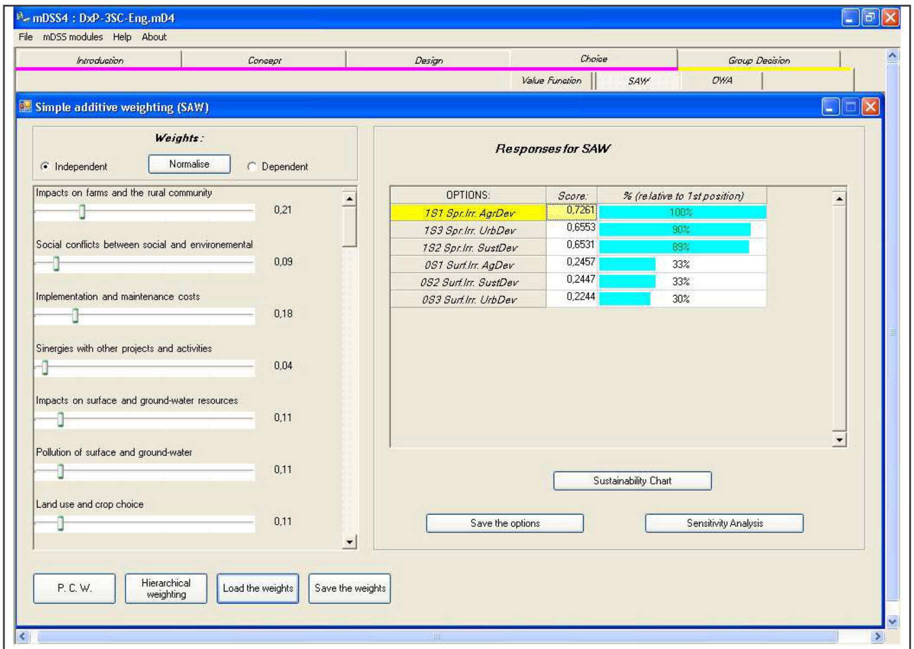


Figure 7.3 SAW (slide 34)

7.5 Ordered weighted averaging

By clicking on OWA on the Tab Bar the OWA window appears. The Ordered Weighted Averaging (OWA) decision rule requires another set of (order) weights describing the risk attitude of decision makers (see decision guide). If the user pushes the OWA button on the TAB BAR, the OWA window appears on the screen.

Unlike the simple weighted average (SAW) the order weights are multiplied to a criterion according to its rank position, rather than according to its individual importance. Although in OWA the weights are still multiplied by the criterion values and then added to give the overall option performance, the association of criterion and weight is different in this case (see for details decision guide). The user may define a curve which describes the distribution of the order weights across the criteria by clicking the icons on the left of the screen.

The weighted criteria values are added to a single overall performance measure. Once that the vector of criterions weight is defined, on the right side of the OWA window appears the Response for OWA. The best option is coloured in yellow and has a score of 100%. The others are ranked in % relative to first position. The four buttons on the bottom simplify the weights assigning. The user may define a curve which describes the distribution of the order weights across the criterions.

Once the analysis has been completed the user might be interested in knowing how robust the final choice is, i.e. how much the weights have to be altered in order to change the ranking of the options. The Sensitivity Analysis can be applied also for OWA responses (see 7.9).

7.6 TOPSIS

By clicking on TOPSIS on the Tab Bar the TOPSIS window appears. With the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) the option which is closer to ideal positive solution and further from the negative ideal solution is considered as being best. Both ideal solutions are described by the extreme criteria performances. Since these solutions are not real and describe only ideal states (which cannot be achieved), the distance of the real options from both of them is combined to make the final choice.

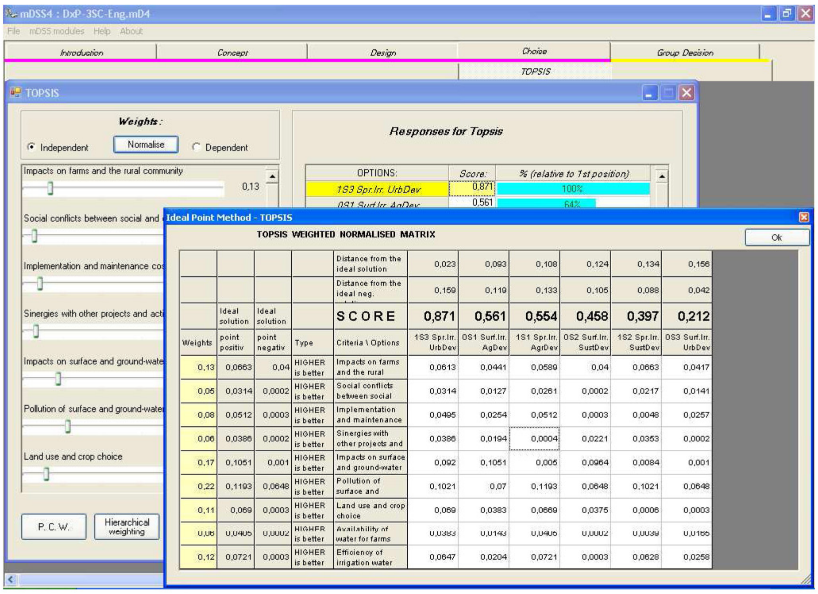


Figure 7.4. TOPSIS (slide 35)

The Topsis Window contains various elements: (i) the data table including standardised and weighted options' outcomes in the central part with white background; (ii) the ideal solutions (the best and worst value for each criterion / row) in the area to the left of the data table; (iii) the current weights in the first column to the left of the frame.

The calculated Euclidian distances from each option (column) to the ideal solutions are shown at the top of the table. The aggregated measure of both distances is showed below and is basis for options' ranking. The weighted criteria values are added to a single overall performance measure. Once that the vector of criterions weight is defined, on the right side of the TOPSIS window appears the Response for TOPSIS decision rule. The best option is coloured in yellow and has a score of 100%. The others are ranked in % relative to first position.

7.7 ELECTRE

uses a different approach to decision support than value/utility function approaches. It bases on a pairwise comparison of the alternatives, so it's computationally more demanding. It imposes so-called outranking relation on a set of alternatives. An alternative a outranks an alternative b if a is at least as good as b and there is no strong argument against. There is a variety of ELECTRE techniques, the ELECTRE III was implemented in the mDSS4. Normally the alternatives have cardinal outcomes in all criteria.

When ELECTRE is marked in the Evaluation Matrix Window and subsequently the Choice button on the tab bar is clicked on, the following window appears (figure 7.5)

This decision rule needs to assign the weights similarly to the previous working session and to fill the three columns of the table on the right of the screen representing the parameters P, Q and T (thresholds). These thresholds stand for ***preference threshold*** (pi), ***indifference threshold*** (qi) and ***veto threshold*** (ti). For a more detailed explanation of their role and meaning, see the description of the "mDSS4 Decision methods".

Once that the table is filled ELECTRE can be started clicking on Run Electre button.

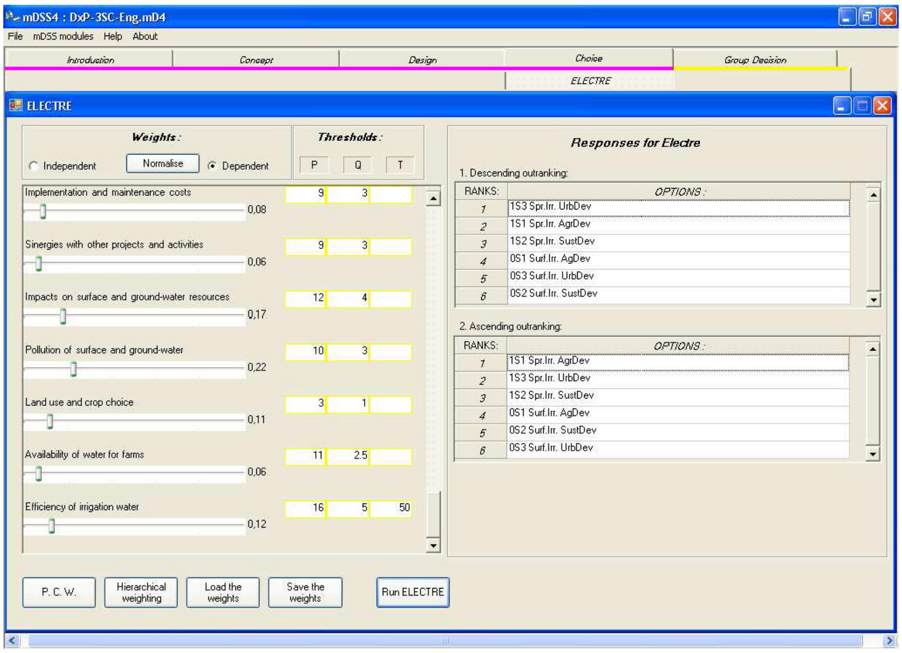


Figure 7.5 ELECTRE (slide 36)

7.8 Sustainability chart

By clicking on the "sustainability chart" button the user may aggregate the evaluation criteria to obtain three macro criteria according their character: environmental, social and economic. The weights for macro criterion are summed and the importance of macro criterion is illustrated in a triangle diagram (Figure 7.6). If all three macro criteria present equal weights, the spot showing the option performance is located exactly in the centre of the triangle. If this spot is closer to one of the corners of the triangle, it means that the corresponding macro criterion overweighs the other two criteria. This chart is intended as an opportunity to evaluate how much the various options are balanced with respect of the three pillars of sustainable development, without considering their overall performance and ranking.

At bottom of the screen appear coloured circles.and black lines. The circles represent the different measures and the areas of the circles represent the score. The length of the black line represents the variability of the criterions.

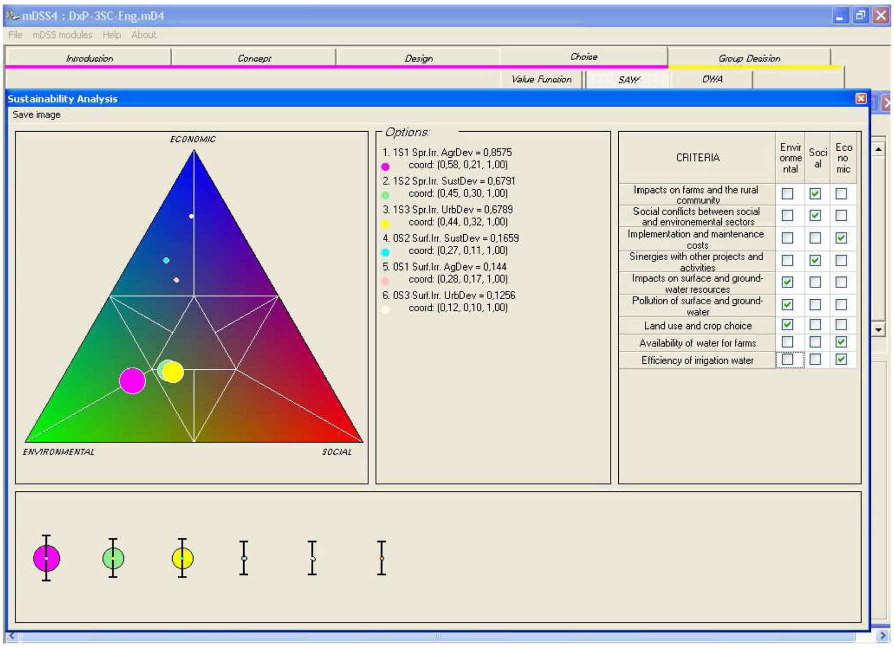


Figure 7.6 Sustainability charts (slide 38)

7.9 Sensitivity analysis

mDSS contains two approaches to SA. The first is called "Most Critical Criterion" and looks for the smallest change in a criterion weight which reverses the ranking of a pair of options. The second is called "Tornado diagram" and provides a visual comparison of the performances of a basic and a challenging option (Figure 7.7).

The most critical criterion (see details in decision guide) is highlighted (green) in the table. Each row in the table describes a possible change in the ranking of two options. The columns describe the criteria and how sensitive are their weights..

The second approach of SA is a visual one and compares two options at a time. The idea behind the approach is to compare the best option with another challenging option. The challenging option may be arbitrarily selected using the list box on the right of the display. The bars shown in the diagram describe each criterion and the possible influence of its weight on the final decision (see decision guide). The orange bars show how stable the best option is with regard to possible changes in criterion weights. If a bar has no orange area, there is no change of the corresponding criterion weight which could reverse the order of the two options. If the orange area is big and close to the red line describing the current difference between the options' performance, then the corresponding criteria may reverse the current ranking with a small change of its weight. The larger are the orange areas, the more stable is the corresponding ranking.

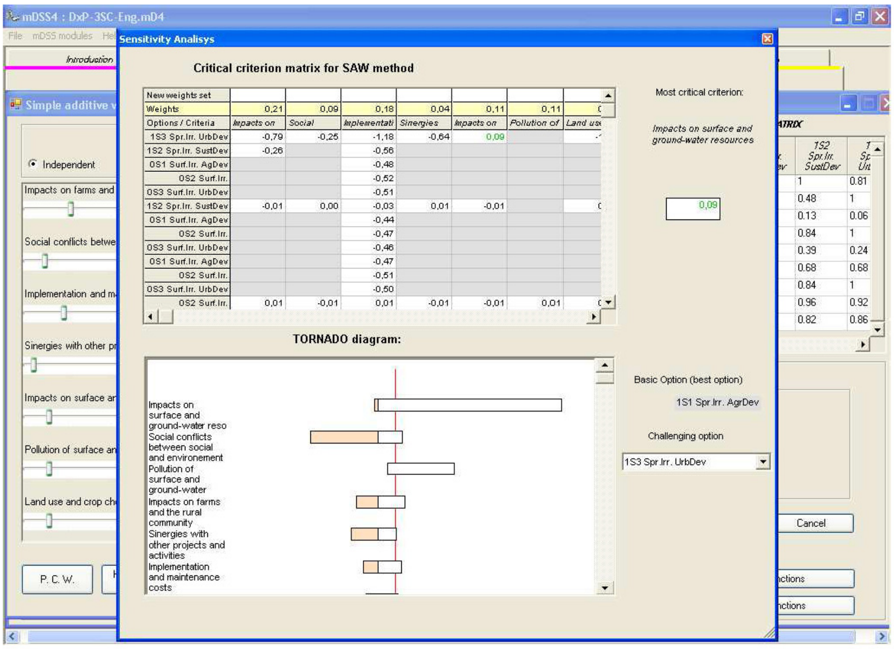


Figure 7.7 Sensitivity Analysis (slide 37)

8. GROUP DECISION ANALYSIS

The situation in which several decision makers have to collaborate and make a common decision is becoming a rule in environmental management. mDSS includes two different approaches when facing such a situation. In the first, the decision makers agree on a common decision model – all members of a decision group are able to find a compromise (through discussion) on a common set of options, criteria and decision rules applied - even though the decision makers may have different judgements with regard to the weights assigned to each criterion. mDSS provides a routine that compares the differences between the weights expressed by different decision makers/interest groups. When the differences are small, the software proposes compromise weights lying somewhere between the indicated sets.

When the judgements are too different (different ranking of options) no compromise solution may be found. In this case the different options are presented and the decision makers or decision group members vote which solution (choice) should be taken. The voting approach implemented in mDSS is based on three different decision rules: Borda, Extended Borda and Condorcet. (see mDSS Decision Methods).

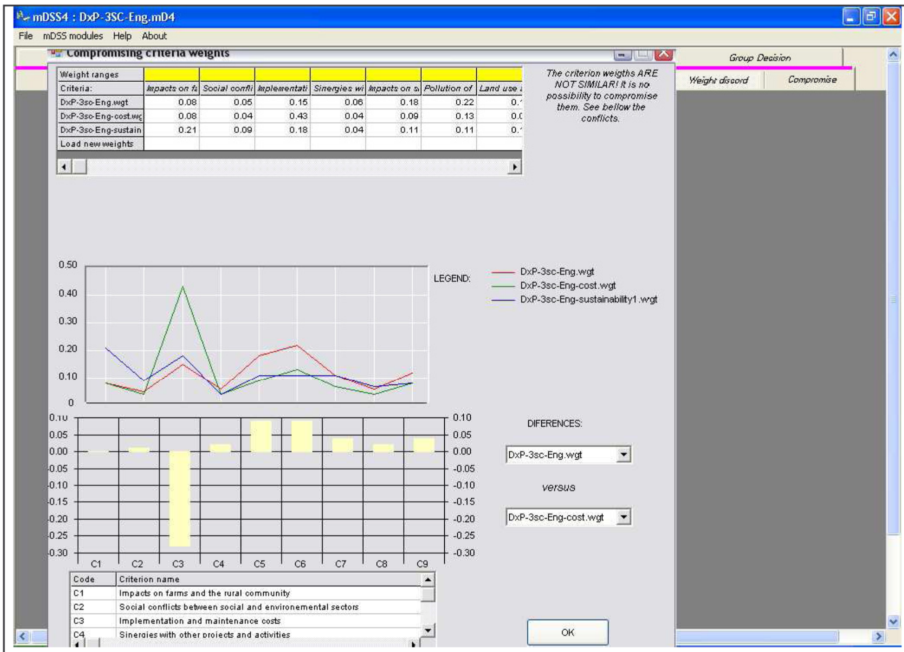


Figure 8.1. Group decision analysis (slide 39)

CONCLUSIONES

CONCLUSIONES

Una vez presentados los diferentes trabajos que forman parte de esta Tesis Doctoral es necesario realizar una serie de consideraciones que nos permitan determinar el grado de cumplimiento de los objetivos que habíamos planteado y que nos permitirán obtener una visión general de la investigación.

Tal y como habíamos establecido desde el inicio del presente trabajo, el objetivo principal de esta investigación era desarrollar, evaluar e implementar un sistema de ayuda a la decisión al amparo de un proyecto de investigación europeo, que permitiera a las administraciones públicas disponer de una herramienta que permitiera manejar una cantidad de información cada vez mayor y más heterogénea, para poder llevar a cabo una gestión sostenible de los recursos hídricos a nivel de cuenca hidrográfica. Para la consecución de dicho objetivo principal nos habíamos planteado una serie de objetivos específicos cuyas conclusiones trataremos de analizar en el presente capítulo.

Uno de los principales retos a los que se enfrentan las administraciones públicas en la toma de decisiones relacionadas con el medio ambiente es la cada vez mayor cantidad de información que ha de ser tenida en cuenta. El caso de la gestión del agua no es una excepción a dicha tendencia a lo que hay que añadir la gran complejidad que suponen los sistema fluviales.

Debido a la gran cantidad y variedad de información, necesaria y disponible, para la toma de decisiones relacionadas con la gestión del agua y a las diferentes fuentes de información disponible las autoridades públicas necesitan herramientas informáticas que les ayuden en los procesos de planificación. Sin embargo en la mayoría de los casos existen dificultades para encontrar un modelo que permita la incorporación e integración de toda la información en un proceso de toma de decisiones.

La metodología MULINO y su evolución NetSymod, así como el sistema de ayuda a la decisión mDSS han sido diseñados con el objetivo de asistir el proceso de toma de decisiones en la gestión del agua desde una perspectiva de sostenibilidad teniendo en cuenta la Directiva Marco del Agua y el nuevo papel que han de jugar las autoridades de cuenca en el proceso de planificación. Del mismo modo se ha intentado que tanto la metodología como el software fuesen coherentes con el enfoque propuesto por la *Estrategia de Implementación Común* aunque durante el desarrollo de los trabajos aquí expuestos no se habían publicado todavía los informes definitivos que debían guiar la implementación de la Directiva.

Pasamos a continuación a describir más detalladamente las conclusiones derivadas de cada en relación a los objetivos específicos que nos habíamos propuesto antes de abordar cada uno de los trabajos para determinar en que medida se han alcanzado los objetivos inicialmente establecidos y su contribución al objetivo general.

1. Definir un enfoque metodológico que permita abordar la mayoría de los problemas decisionales que se plantean en la gestión integrada del agua desde el punto de vista de las administraciones públicas.

Una de las principales conclusiones que se pueden extraer en relación a este objetivo es la constatación de la complejidad a la que se tienen que enfrentar las autoridades públicas en los procesos de gestión integrada del agua. El análisis al respecto de la literatura existente y el trabajo empírico realizado fundamentalmente en los dos casos de estudio presentados nos han reafirmado en la necesidad de plantear una metodología específica en este campo.

Tras el análisis de la literatura relacionada con la gestión del agua y el análisis multicriterio se puede concluir que desde los primeros trabajos en Investigación Operativa a inicio de siglo XX, ha sido numerosos los métodos de toma de decisiones multicriterio que se han desarrollado y aplicado a problemas relacionados con la gestión del agua. En términos generales, se puede afirmar también, que la gestión integrada del agua constituye en si misma un problema de decisión multicriterio. Las primeras aplicaciones a este campo en la década de los años 70, estaban más orientadas a contextos decisionales de carácter operativo que trataban de resolver problemas altamente estructurados que debían ser resueltos por un único decisor. La evolución hacia un enfoque más integrado del agua, ha marcado la evolución de estos métodos de evaluación bajo este Nuevo paradigma.

Del mismo modo de la adopción del principio de sostenibilidad que ha de guiar todo desarrollo humano, se puede extraer la evidencia y necesidad de que son necesarias metodologías y herramientas que nos permitan poner en la práctica dichos principios. Todo ello, en un ámbito de aplicación en el cual el apoyo a las decisiones y las soluciones, en términos de sostenibilidad, se haga no solo con un horizonte temporal a largo plazo, sino también teniendo en cuenta la contribución a la perspectiva de desarrollo sostenible desde las actividades del día a día. Esto ha de permitir a los decisores, metodologías que permitan, primero tomar sus decisiones pero también controlar los procesos y efectos derivados de tales decisiones. El concreto de gestión integrada del agua podría concebirse dentro de este ámbito, ya que requiere enfoques y metodologías *ad hoc* adaptados a las necesidades específicas y a las particularidades de los recursos hídricos.

El desarrollo en los últimos tiempos de cada vez mayor número de políticas ambientales ha dado lugar a la necesidad de conseguir, de alguna manera, un mayor control e integración de la cantidad de datos y del conocimiento científico, que cada vez está más disponible, y que pueden apoyar la gestión integrada del agua.

El enfoque metodológico propuesto, y que subyace en el software mDSS, creemos permite a las administraciones públicas no solo abordar de manera genérica una amplia gama de problemas decisionales a nivel estratégico bajo la perspectiva de la sostenibilidad, sino que además se convierte en un instrumento de comunicación entre las diferentes administraciones públicas con competencias en materia de agua. La representación de los diferentes puntos de vista sobre una base común puede permitir una plasmación mucho más transparente del proceso decisional y con ello un punto de partida sólido para la resolución de conflictos. Estimamos que la metodología presentada combina la potencialidad innovadora de la gestión integrada y del análisis multicriterio, con el eficaz potencial de comunicación que proporciona el marco conceptual DPSIR.

2. Establecer un marco de referencia conceptual de la gestión sostenible de los recursos hídricos.

La concienciación creciente y el desarrollo de una gran cantidad de normativa, políticas, programas y planes en materia ambiental ha dado lugar a una amplia gama de términos y conceptos que creemos necesario precisar, para alcanzar el objetivo principal. En la mayoría de los casos, bien sea por el diferente momento en que han salido a la luz o por la diversa procedencia de los mismos, nos lleva a creer que es necesaria también una integración de conceptos.

Esta integración creemos que se representa en el marco de referencia conceptual propuesto y que parte de la definición de gestión integrada del agua establecida por Bogardi (1994). Esta aportación permite establecer y aclarar de una manera lógica los conceptos y terminologías utilizadas habitualmente en la gestión del agua y los recursos naturales y las relaciones entre los mismos.

Este marco de referencia conceptual propuesto junto con el enfoque metodológico descrito conforman la base necesaria para poder establecer una metodología que permita la resolución de problemas en la gestión del agua tal y como se indica en los requerimientos de la Directiva Marco del Agua.

En los últimos años varios métodos de control y supervisión ambiental, herramientas de análisis y modelización y los estudios de evaluación del impacto ambiental, han demostrado su utilidad a la hora de proporcionar una visión del funcionamiento y comportamiento de los sistemas ambientales y los problemas que de ellos se derivan.

Si embargo, la integración de dichos métodos y herramientas, y lo que es más, de los conceptos que manejan es todavía hoy una asignatura pendiente. Creemos que el marco de referencia conceptual propuesto, fundamentalmente en el capítulo X ha permitido a los decisores, actores y usuarios en materia de agua, tener una visión más detallada y clara de la terminología utilizada habitualmente en las actividades de gestión del agua.

El proceso de 4 pasos descrito en el capítulo X, creemos que puede contribuir establecer un marco de referencia conceptual que permita a su vez proporcionar un soporte metodológico a esta tipología de problemas teniendo en cuenta:

- la complejidad de contexto decisional típica de la gestión integrada del agua;
- la gran cantidad de información multisectorial y multidisciplinar;
- la necesidad de una comunicación más eficiente entre el sector público y los decisores, y el resto de actores involucrados o afectados por las decisiones.

Se ha observado además, que el esquema DPSIR propuesto, ha demostrado ser lo suficientemente amplio y genérico para permitir la formalización de todo el procedimiento de toma de decisiones en el contexto de la gestión sostenible del agua. Sin embargo se necesita realizar ulteriores esfuerzos de análisis, tanto teóricos como metodológicos, para desarrollar una herramienta integrada y dinámica de ayuda a la decisión sobre esa base.

3. Establecer mecanismos de participación publica en los procesos de planificación del agua.

Tal y como establece en su artículo 14, “el éxito de la presente Directiva depende de una colaboración estrecha y una actuación coherente de la Comunidad, los Estados miembros y las autoridades locales, así como de la información, las consultas y la participación del público, incluidos los usuarios”. La introducción de este artículo supone un avance en los modelos de gestión de los recursos públicos pero al mismo tiempo implica una gran complejidad a la hora de hacerlo efectivo en la práctica.

Este proceso de participación pública que se describe de manera más precisa en el documento nº 8 de la Estrategia de Implementación Común resalta que, aunque si bien es necesaria, existe una gran complejidad a la hora de establecer mecanismos que permitan una comunicación efectiva y transparente entre la esfera política, el mundo científico/técnico y la ciudadanía.

Creemos en este sentido que el enfoque metodológico propuesto basado en el análisis multicriterio y el uso del modelo DPSIR en su fase de conceptualización conforman un adecuado mecanismo que sirva como referencia de base para el proceso de participación pública. Se puede decir que en el propio desarrollo de la metodología se ha seguido esta filosofía de participación pública, contando en todo momento con la colaboración de usuarios y actores en los diferentes casos de estudio del proyecto Mulino en el seno del cual se enmarca esta tesis de doctorado.

Hemos constatado que la transparencia del modelo hace que su estructura sea fácilmente entendible, y la capacidad de comparación de resultados desde diferentes puntos de vista permiten una base de discusión común, ya sea de forma conjunta o por separado. No obstante, la escasez de aplicaciones de esta metodología fuera del ámbito de la realización de informes ambientales, hace que sea necesario una investigación en mayor profundidad, al no estar totalmente clara su implementación de manera efectiva en un proceso de toma de decisiones con participación pública.

Este tipo de marcos conceptuales representan en cualquier caso, una herramienta muy útil para la conceptualización de problemas, ya que permite establecer una relación holística causa-efecto de manera comprensible incluso para aquellos que carecen de los conocimientos técnicos necesarios en materia de impacto ambiental. La representación del modelo DPSIR, tiene como base un modelo simple de mapas cognitivos y aunque en su desarrollo se presente cierta complejidad a nivel técnico (no operativo), su representación es intuitiva y de fácil asimilación, tanto para expertos como no expertos.

La adopción de este esquema DPSIR ha sido desarrollada en un instrumento operativo de ayuda a la decisión en el seno del proyecto MULINO, desarrollando una teoría innovativa y nuevas metodologías con el objetivo de transformar el estático esquema actual de información ambiental en un marco de trabajo dinámico para la modelización integrada (IAM) y demás procedimientos de evaluación.

4. Diseñar y desarrollar de una herramienta operativa de ayuda a la decisión que permita integrar modelización hidrológica, indicadores e índices multidisciplinarios y procedimientos de análisis multicriterio para la gestión del agua.

La revisión de un importante número de trabajos nos sirve para constatar que a lo largo de estos años se han utilizado un gran número de métodos en el campo de la gestión integrada del agua en diferentes contextos y con diferentes propósitos. Entre las razones esgrimidas para el uso de este tipo de métodos, cabe destacar la habilidad de estos para proporcionar a los decisores una mejor comprensión de los problemas derivados de la gestión del agua y la posibilidad de explorar diferentes puntos de vista de su percepción. En cualquier caso, parece evidente que la tendencia en los últimos años es a realizar mayores esfuerzos en constatar la aplicación práctica de estos métodos que en el desarrollo de nuevas métodos. Se puede afirmar que en general han sido numerosos los logros obtenidos de la aplicación de estos métodos, sin embargo también han surgido nuevos problemas.

Se puede concluir tras el análisis realizado que los diferentes autores se han encontrado con una serie de problemas a la hora de enfrentarse al desarrollo y consiguiente traslado a la práctica sus métodos.:

El primer grupo de problemas tiene que ver con la información disponible. Muchas de las contribuciones analizadas han tratado de superar el hecho de incluir exclusivamente información de carácter técnico incluyendo aspectos socio-económicos de una forma más integrada. No obstante, la ausencia de información apropiada para llevar a cabo el proceso de evaluación parece ser por el momento el problema más relevante. En unas ocasiones este problema se produce por aleatoriedad de los escenarios futuros y en otras por la falta de conocimiento científico por parte de los expertos. En general puede decirse que la incertidumbre sobre los posibles efectos de las diferentes alternativas ante las que se enfrentan los decisores es muy elevada. Por esta razón algunos de los métodos analizados han incluido el uso de conjuntos borrosos en sus aplicaciones.

El segundo grupo de problemas está relacionado con la opacidad que presentan los métodos y la toma de decisiones en la gestión integrada del agua. Los decisores, que en la mayoría de los casos son cargos de carácter político y no poseen siempre una formación técnica suficiente, tienen recelos para aceptar métodos excesivamente complicados aún en el caso de que sus aplicaciones dispongan de un interfaz de usuario bastante accesible. Si los algoritmos utilizados son lo suficientemente complejos para que puedan ser comprendidos por el decisor, el proceso decisional se convierte en una caja negra. Esto provoca cierta desconfianza y recelo a la hora de afrontar una toma de decisiones en grupo.

En tercer lugar, las administraciones públicas que tienen la responsabilidad de tomar decisiones en lo que respecta a la gestión del agua, no poseen una gran experiencia en la aplicación de este tipo de metodologías de toma de decisiones multicriterio. En ocasiones la complejidad de la gestión de este tipo de recursos hace necesaria la realización de estudios que entran en conflicto con los criterios de tiempo y coste que caracterizan los procedimientos administrativos. En cualquier caso se constata que la administración pública es consciente de que ya no es posible tratar de evaluar este tipo de problemas, pero al mismo tiempo la aplicación del análisis multicriterio en el mundo real es complicada desde el punto de vista institucional.

El último grupo de problemas hace referencia a la complejidad que supone la existencia de un grupo de decisores, en lugar de uno, con diferentes puntos de vista que en ocasiones pueden entrar en conflicto. De este modo se hace más patente la inclusión de los aspectos de la toma de decisiones en grupo, como parte de la metodología para afrontar este tipo de problemas con el fin de proporcionar un análisis que permita una mayor interacción y colaboración .

Se puede afirmar que la tendencia en los últimos años es a utilizar los métodos multicriterio menos complejos en cuanto a sus algoritmos en detrimento de los que presentan una metodología más desarrollada. Este tipo de métodos menos complejos y de mayor comprensión pueden ser utilizados en determinadas situaciones facilitando un mayor grado de transparencia en el proceso decisional.

En cualquier caso es necesario incorporar un marco conceptual bien definido que permita el análisis de políticas y su priorización para guiar la toma de decisiones en el ámbito de la gestión integrada del agua resaltando la importancia de la estructuración de problemas, el uso de información técnica de combinada con juicios de valor a través de una implicación activa de todos los actores involucrados en el proceso.

5. Probar la herramienta en casos de estudio representativos con la colaboración tanto de los actores implicados como de los usuarios finales del software.

Generalmente el análisis de la toma de decisiones ayuda a desarrollar una estructura para la conceptualización del problema, un lenguaje para expresar los aspectos más relevantes y una forma de de combinar diferentes puntos de vista. Teniendo en cuenta esto, se ha de poner más énfasis en el proceso decisional que en los resultados obtenidos del mismo.

La metodología Mulino ha demostrado ser una herramienta muy útil en el contexto decisional planteado en los dos casos de estudio presentados en esta tesis: la evaluación de alternativas para la construcción de un acueducto en la península del

Cavallino y el análisis de las motivaciones que guiaron el proceso de decisión de la construcción de la presa de *Ceyhan Aslantas*.

En el caso del Cavallino, el uso de la metodología MULINO y en particular el Análisis de Redes Sociales y el software mDSS, han mostrado su potencial para formalizar y estandarizar el proceso decisional, permitiendo un análisis paralelo, coherente y comparable, de las distintas formas en que abordarían el proceso decisional los diferentes actores implicados.

El mDSS ha demostrado a su vez ser una muy eficaz como herramienta de comunicación entre el ámbito técnico y el ámbito político de la administración, al cual le ha proporcionado un instrumento de comunicación más eficiente y transparente de complejos procesos e información técnica. En la práctica el mDSS ha sido utilizado tanto para implementar los resultados del estudio de impacto ambiental desarrollado por la "Asociación para el Saneamiento del *Basso Piave*" y que fue presentado ante la Comisión de Impacto Ambiental de la Región del Veneto, como para el análisis de las alternativas de tratamiento de aguas de la alternativa seleccionada.

Por otro lado se ha constatado que el uso del mDSS, requiere una formación previa e invertir una cierta cantidad de tiempo para aprender a utilizar la herramienta. Este proceso de aprendizaje familiarización creemos que es inherente al uso de cualquier sistema basado en ordenador, aunque para facilitar el aprendizaje autónomo se ha incluido una guía de usuario y un caso de estudio de referencia.

A raíz de este mismo caso de estudio se puede concluir que el marco conceptual propuesto (DPSIR) en la fase de estructuración ha demostrado su utilidad para clarificar los antecedentes del problema, pero en alguna ocasiones puntuales ha resultado subjetivo y ambiguo. De igual forma en el estudio se ha mostrado la utilidad del mDSS tratando de mostrar las diferencias presentadas en los juicios de valor de un determinado número de actores.

En el estudio exploratorio del contexto decisional llevado a cabo en el caso de la presa de Aslantas, el enfoque DPSIR ha demostrado ser un soporte consistente en la fase de estructuración del problema, mientras que la evaluación multicriterio ha proporcionado una guía muy efectiva a lo largo de proceso decisional, del mismo modo que el análisis de sensibilidad y sostenibilidad propuesto en el software.

La posibilidad de realizar un análisis de escenarios ha demostrado disponer de elementos potenciales concretos para el estudio de los posibles efectos de la incertidumbre y de las diferentes perspectiva o puntos de vista en la decisión final. En el análisis de sostenibilidad, por ejemplo, el análisis de la media y la desviación típica de los criterios, permite estudiar los efectos compensatorios de los métodos de agregación como el SAW (simple additive weighting).

A diferencia del caso del Cavallino donde se han utilizado básicamente juicios de valor de expertos en la construcción de la matriz de análisis, en este caso el mDSS ha servido de ayuda para gestionar la gran diversidad de información procedente de este caso: largas series temporales, amplia áreas de terreno, información multidisciplinar, incertidumbre y diferentes unidades de medida.

Ayudando a divulgar explícitamente las asunciones de partida y los intereses implicados en un contexto de decisión como el presente, con el uso del mDSS se obtiene una doble ventaja. En primer lugar, el proceso de decisión se hace más transparente. En segundo lugar, permite simular y explorar a priori y a posteriori, los diferentes puntos de vista de un problema

En ambos casos y en lo que se refiere al mDSS, creemos que son necesarios ulteriores mejoras en la metodología con respecto a la estructuración del problema, al análisis de resultados y en el análisis de sensibilidad, lo que consolidaría aún más la aplicabilidad del mDSS. En concreto se necesita prestar especial atención en los siguientes aspectos:

En la fase conceptual, la estructuración de problema necesita ser revisada para que tanto los criterios descriptivos como los numéricos o normativos puedan ser identificados y mejorar así el potencial analítico de la herramienta del mDSS con respecto al desarrollo sostenible. Los criterios seleccionados en la fase conceptual, representan las cadenas causa-efecto que caracterizan el funcionamiento del sistema. Las prioridades estratégicas o las directrices que se establezcan en relación a los criterios específicos de sostenibilidad no se respetan si no se tienen en cuenta los elementos de equidad, equilibrio entre los sistemas económicos, ambientales y sociales, así como los derechos afectados y los riesgos percibidos.

En la fase de diseño, el análisis multicriterio utiliza un solo valor para representar el resultado de un criterio inducido por una opción o alternativa dada. En determinadas circunstancias es necesario comparar no sólo la situación *ex ante* y *ex post* de un proyecto, sino que los progresos que se realicen también necesitan ser comparados. La agregación de los resultados en un solo valor, como se propone en los métodos aditivos, requiere evitar influencia de la preferencia de temporal. En lugar y con objeto de proporcionar una mayor transparencia, se podría analizar el potencial que supondría introducir en el mDSS, las matrices de análisis que representan las distintas fases de la vida de un proyecto;

En la fase selección, necesita revisarse en el análisis de sensibilidad la variación sistemática de los pesos de un criterio, así como de los valores de los resultados y de las funciones de valor utilizadas. Un posible punto de partida para la evolución futura del software. Un punto de partida posible para futuras mejoras del mDSS sería tener en cuenta las diversas causas de incertidumbre que influencia el análisis multicriterio. Incluso si los criterios individuales se pueden predecir con cierto grado de exactitud, la metodología de la evaluación multicriterio puede ponerse en cuestión debido al impacto que la incertidumbre ocasiona en el resultado total.

A modo de resumen, el resultado del trabajo presentado en esta tesis es una contribución al desarrollo de una metodología y el diseño de software que pueda ser aplicada para un llevar a cabo un enfoque integrado de los problemas decisionales relacionados con la gestión del agua. El software incorpora elementos de análisis integrado de modelización (IAM), análisis multicriterio(MCA) y el modelo DPSIR de la Agencia Europea de Medio Ambiente, adoptando formatos de datos utilizados de forma genérica en la actualidad para garantizar interoperabilidad con otros sistemas. Para el uso del sistema no se requiere ningún software adicional, lo que permite mejorar su potencial de utilización por parte de los responsables de la gestión del agua. Del mismo modo el software permite la importación de datos e información de sistemas de información geográfica y cualquier modelo hidrológicos que respete un procedimiento de input/output estándar.

El software MULINO DSS “mDSS” el software fue publicado en 3 versiones (mDSS1, mDSS2 y mDSS3) a lo largo del proyecto, siendo presentada la primera versión a los usuarios finales del proyecto antes del final del primer año. La implicación desde el inicio de los potenciales usuarios finales demostró ser una eficaz estrategia para el éxito del proyecto, permitiendo que la investigación desarrollada, y que en parte ha sido presentada en esta tesis, adaptara progresivamente el desarrollo de software a sus necesidades. El sistema ha experimentado cambios significativos desde el lanzamiento del primer prototipo, como resultado del feedback de los socios del proyecto y de los potenciales usuarios finales. Ejemplo de ello son las rutinas empleadas en el software para implicar a diferentes actores en un proceso de toma de decisiones grupal

Desde la finalización del proyecto en diciembre de 2003, el software ha continuado siendo desarrollado por los autores del mismo. Posteriores contribuciones como las que se presentan en este trabajo de tesis doctoral han sido incluidas siguiendo la misma filosofía del proyecto de involucrar a los potenciales usuarios del sistema. La metodología y el software han sido utilizados en diferentes proyectos europeos como TRANSCAT, DSS-GUIDE, NOSTRUM-DSS, NEWATER y BRAHMATWIN. De igual forma el modelo se ha utilizado a través de un acuerdo con el Ministerio del Medio Ambiente italiano en el proceso de desarrollo del Plan Hidrológico de la cuenca del Cecina (Italia), una de las cuencas piloto para la implantación de la Directiva Marco del Agua y que todavía está en fase de realización.

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