

A TECHNICAL REVIEW OF THE SPANISH NATIONAL HYDROLOGICAL PLAN (EBRO RIVER OUT-OF-BASIN DIVERSION)

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1.0 EXECUTIVE SUMMARY

This report provides a technical scientific and engineering review of the Spanish National Hydrological Plan (Plan) for water transfers from the Ebro River south along the Mediterranean Coast to the Jucar, Segura and south Almeria basins and north to the internal basins of Catalonia. The project involves the transfer of 6% of the natural annual flow of the Ebro River, which amount to about 9% of its current flow. Exported water will be used for agricultural, urban, and industrial supply, as well as ecosystem restoration. Agriculture is the main proposed water use. The conclusions and recommendation stated in this report are based on study of the Plan and associated documents, site visits and hearings in the Ebro region and the proposed terminus in June 2002, and the team's extensive experience with water transfers in other semi-arid regions, especially California and the southwest USA.

Our main conclusions are that the Ebro River diversions are well founded in terms of hydrology (water available) and water resources (need for water). The diversion of the relatively small percentage of Ebro River's annual flow will have small ecological consequences in the now degraded and highly modified Lower Ebro River and Delta. Rather than reacting to the small negative effect of the proposed diversion we recommend that the Plan be developed proactively with the eventual goal of solving the much larger ecological problems that now exist in the Ebro River, its Delta and the Spanish Mediterranean coastal wetlands. These larger ecological problems are primarily poor water quality and habitat loss. If it can be accomplished, the exchange of a small quantity of Ebro River water for a large improvement in water quality would be ecologically desirable. The restoration of river flood plains, the reversal of eutrophication, the cleansing of polluted water, and the optimisation of the salt wedge location, are often impossible ecological dreams. In the case of the Ebro, these dreams can be realized if the proposals contained in this report are developed and incorporated into the Plan. In particular, we recommend the use of wetlands to reverse eutrophication and other pollution in the Ebro River as well as provide flood control, flood plain management and expanded wildlife habitat. The Plan as it now exists does aim to provide some local and regional ecological restoration and enhancement, but the details of the actions to be taken were not complete.

Sustainability is a main requirement for water projects as well as any ecosystem restorations. The Plan should therefore be developed to provide a fully sustainable solution to the ecological, agricultural, and urban and industrial water needs. It is important that careful regulation and monitoring of groundwater extraction continue as part of the Plan to ensure that over-drafting ceases or is reversed. We suggest refinements to the Integral Plan that would restore sustainable ecological values in the Ebro River, its Delta, and the Mediterranean wetland chain that constitutes a major bird flyway. We recommend that the project be developed as "A Restoration and Enhancement Plan for Sustainable Ecology and Agriculture for the Spanish Mediterranean". The developed and expanded Plan should focus on providing "win-win" solutions to the wide range of water-related problems that currently exist in the Lower Ebro River, the Ebro Delta, the coastal wetland chain, and depleted groundwater.

The report details our findings and recommendations on the original Plan in the areas of hydrology, ecology, economics, and water resources and makes comparisons with other semi-arid water transfer projects. These are based on our technical analysis of the Plan and its feasibility in light of our own knowledge and experience.

In conclusion, we find that The Plan will provide adequate water for urban, industrial, agricultural, and ecological uses in the Mediterranean region. Nonetheless, some further development of the Plan needs to be conducted incorporating restoration of the Ebro River and Delta, other coastal wetland restorations, off-line regulatory storages, and provisions for long-term research studies. If our recommendations for ecological restoration are carried out, the entire Spanish Mediterranean coastal ecosystem will be considerably enhanced.

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3.0 INTRODUCTION

High value agricultural crops grow well in semi-arid climates such as California and Spain. The extent of agriculture in these dry areas depends on a reliable supply of water. Climatic, socio-economic conditions encouraged the development of irrigated agriculture in the Mediterranean region from ancient times, with major increases between 1950 and 1990. During these years, groundwater use was fully developed and a transfer from the Tagus River Basin was constructed and operated. Unfortunately, the increased level of agricultural development has become unsustainable. Some irrigated areas have been abandoned and ground water aquifers have been overdrawn and depleted. New imported water supplies are needed to continue the current level of irrigated agriculture and eliminate ground water overdraft in these regions. In addition, the rapid increase in urban and recreational development in the region also requires supplemental drinking water supplies.

To solve these and other problems, the Government of Spain devised a Spanish National Hydrological Plan (SNHP, the "Plan"). The Plan was ratified via the National Hydrological Plan ACT 10/2001, on the 5th of July 2001. Some of the capital costs of the plan are to be born by the European Union (EU) and the remainder by Spain. Thus, the Plan must satisfy the policies of both Spain and the EU.

The Plan must be based on sustainable development, sound engineering, science and economics and provide environmental protection. Above all, the Plan must be ecologically sustainable into the distant future. The Plan proposes a transfer of water from the wet northeastern part of Spain to the arid eastern Mediterranean coastal region. The water source is the Ebro River, Spain's largest river. The Plan has many similarities with major water transfer projects in the southwestern regions of the United States of America, including California and Arizona

The expert team assembled for this review represents 200 years of experience with water projects in the western US and other arid and wetter parts of the world. The team provides expertise in Ecological Engineering, Water Resource Engineering, Aquatic Ecology, Surface and Ground Water Hydrology, and Agricultural Economics. The team includes four members who have direct experience with large water transfer project negotiations in the western US. The team also includes members with worldwide ecological research and management experience in wetlands, rivers, lakes, estuaries, and oceans. This report by the U.S. Technical Review Team is based upon a review of the available documentation from both pro and con sources; site visits in Spain, and numerous briefings on various aspects of the project.

4.0. INTEGRATED OVERVIEW

4.1 FINDINGS

This report is a technical scientific and engineering review of the Spanish National Hydrological Plan (Plan) concerning water transfers from the Ebro River south along the Mediterranean Coast. Political and detailed legal considerations are not part of our mandate. In addition, we have taken both a broad view based on our world-wide experience and a more narrow view based on the Plan and its supporting documents as well as other literature that is available on the topic. Our conclusions and recommendation are based on study of the Plan and associated documents, site visits and hearings in the Ebro region and the proposed terminus in June 2002, and the team's extensive experience with water transfers in other semi-arid regions, especially California and other parts of the arid southwestern United States of America.

4.1.1 The need for water in the region

The need for the water transfer is mainly driven by the need to reverse the over-drafting of groundwater aquifers in regions to the south of the Ebro Delta. Although progress has been made in the last few years to stabilize over-drafting in at least some of the southern agricultural districts, the current situation is not sustainable since in some areas the groundwater level has fallen over 400 meters below the surface. The Plan aims to restore groundwater to more appropriate levels by stopping groundwater pumping in selected areas. The general overuse of water has had ecological consequences caused by a lack of water and by a degradation of the water quality in the supply to some aquatic ecosystems. The ecological problems stem in large part from the fact that the brackish water and productive coastal wetlands and natural areas are often supplied with nutrient-rich irrigation return water, sometimes from rice farming. The Ebro Delta and its wetlands suffer similar water quality problems since they lie around the fringes of the large Delta farm region.

Imported water is to be used for agricultural, urban, and industrial supply but also for environmental purposes in the Ebro Delta. Importantly, the Plan also intends to include ecosystem restoration of wetlands in the Mediterranean coastal regions south of the Ebro Basin. We support the use of clean imported water for ecological enhancement where needed.

4.1.2 Hydrologic analysis

The basic concept of the Plan is to divert a relatively small proportion of the natural flow of the Ebro River for use outside the basin. The diversion volume is 6-9%, depending on possible future upstream consumption and the assumptions of current diversions of the river flow (Table 1). The amount of water to be diverted was determined as the minimum amount that would balance the non-sustainable groundwater extraction and surface waters in the Mediterranean regions plus urban requirements for cities along the canal route. The Plan is specific in that it prohibits the use of the imported water to expand agriculture into new areas. The amount currently used in the Ebro River basin is a net

value and includes diversions for agriculture, consumptive use by the crops, and return flows from the agricultural fields.

Table 1. Mean annual discharges and current and proposed in-basin use and out-of-basin diversions in the Ebro River.

Description	Flow hm ³ /yr	Percent of historical flows	Percent of present flows	Comment
Natural historical mean discharge	~17,300	100	-	Reconstructed unimpaired historical flows at Tortosa for 1940 - 1996
Natural low	~8,000	-	-	As above
Natural high	~30,000	-	-	As above
Current upstream mean use	~5,500	32	48	Mostly consumptive agricultural use
Current mean discharge	11,500	67	100	Upstream losses from irrigation & evaporation behind dams
Mean expected discharge after full build-out upstream	~8,800	51	77	Assumes all future upstream net consumptive use
Minimum historical mean flow (~50 m ³ /s)	~ 1,500	~ 9	13	Salt wedge moves up to upstream edge of delta
Minimum flow after SNHP diversion of 100 m ³ /s.	3,300	18	27	Proposal may be too high for some wildlife concerns in the estuary during some years
Volume available to divert	5,200	30	45	Volume above 100 m ³ /s minimum flow not allocated for future use
Proposed out of basin diversion	1,050	6	9	SNHP based on overdrafts in the south
Mean flow after SNHP + full development	4,150	25	36	Ultimate consumptive use of water assuming all upstream development and out of basin diversions.

In order to estimate the percentage of water to be diverted it is necessary to calculate the natural or virgin flows in the Ebro River. Over the last hundred years the natural flows have been altered by upstream diversions for irrigation, urban water extraction and evaporation behind numerous dams. The natural flows were determined via a series of pseudo-historical virgin flows at Tortosa (1940-96). A statistical analysis of synthetically generated flows was used to develop the amount of stream flow available for diversion from the Ebro River. The virgin flow time series was used to estimate the needed hydrologic parameters (mean values, variances, and autocorrelation coefficients) that characterize the natural statistical structure of monthly and annual level discharges at Tortosa. The parameters were then used to generate stream flows statistically indistinguishable from the virgin series in 1940-1995, both at the monthly and at the annual scales. The new synthetically generated stream flows allow the Plan to make an estimate of the probabilities of failure under different scenarios of demands and transfer. For example, the number of times that low flows would occur could be estimated with more certainty.

4.1.3 Current ecological problems in the Ebro River, its Delta and the coastal wetlands chain south to the Mediterranean regions.

Most of the problems of the Ebro River, its Delta and the chain of brackish water wetlands all along the Mediterranean Coast have been described in detail in many publications. They range from anoxia (low or zero dissolved oxygen) in the estuarine salt wedge and brackish water wetlands to toxicity and loss of various kinds of habitat to total extinction of species like the sturgeon. Most of the problems are due to pollution or water quality degradation. Others are due to loss of habitat such as the removal of riparian corridor or the almost total loss of the flood plain in the lower river. Only a few problems such as loss of clean gravels are partially due to simple decreases in flow, and even then only partially so.

While some water quality problems may be due to decreased current velocities, increasing the flow of polluted water to the Delta or its fringe wetlands does not seem to be a viable or sustainable solution. Similarly, a small decrease in the flow of polluted water would not cause much degradation either. Keeping the flow at the current levels would maintain the current poor ecological health in the region. More than volume is involved if the ecosystem is to be restored or enhanced.

The productivity of the main stem Ebro River and its Delta depend on two main habitats; the flood plain and the salt wedge. The flood plain includes the riparian fringe but most importantly wetlands and pools more distant from the river but still subject to flooding. The salt wedge is confined to the estuarine reach of the river and is the region where light fresh water mixes with denser seawater. Both of these habitats are now almost lost, degraded by pollution, or both. *The restoration of the Ebro does not depend on maintenance of current river flow, or increases or decreases in current river flows, but in habitat restoration combined with a flow of clean water of adequate volume and delivered at an appropriate time.*

The flood plain is the source of much of the food required by fish in larger rivers such as the Ebro. There is a general relationship between fish diversity or biomass and the area of the flood plain. Most comments here concern the flood plain above the Delta since most of the Delta's flood plain is used for rice farming. The flood plain along the Ebro River is needed since rivers are poor sites for primary production being too muddy, abrasive and stirred to promote algal or macrophyte growth, even though nutrients are naturally elevated in rivers relative to the headwaters. In contrast, the flood plain provides a good source of high quality protein for fish that can find stranded insects as well as seeds and some other vegetation. The riparian fringe provides a lesser amount of food than the flood plain but has other uses as well such as provision of snag and root habitat.

The numerous dams along the Ebro reduce the supply of inorganic sediment to the river gravels and the Delta. Dams, especially the two large hydropower dams not far upstream for the Ebro Delta, block the migration of fish and invertebrates. Finally, the water quality of the dam deep-water outflows is likely to be poor and possibly toxic.

The Ebro River is polluted, like many rivers that host cities and industry along its banks and agriculture in its flood plain. The pollution is from point sources such as the discharge of treated and semi-treated sewage, industrial waste, and some aerial fallout. The effects of this pollution can be seen in the nutrient levels in the river that promote eutrophication and low dissolved oxygen concentrations at night or in deep water. The pollution can also be seen in the potentially toxic chemicals (heavy metals, human derived toxic organic compounds) now present in the water of the Ebro and its sediments (especially the reservoir sediments). The non-point or diffuse sources of pollution includes pesticides and nutrients from agricultural runoff and urban runoff.

The salt wedge in the Ebro Delta forms where the less dense freshwater floats over the dense seawater. At this point the flocculation of organic particles carried down by the river is caused by the high cation (positively charged ions such as sodium or magnesium) content of the seawater. The flocculated organic particles are food for some aquatic organisms and are not swept out to sea along with the rest of the river water due to the back and forth motion of changing flows that characterizes estuaries. Other living particles such as phytoplankton, zooplankton and small fish take advantage of this stable food-rich refuge, which is typically the most productive region of the estuary. The salt wedge is naturally eutrophic but can become over-eutrophic with the addition of nutrients, especially nitrate. If anoxia occurs due to depletion of oxygen by the decay of excessive algae blooms the biological value of the salt wedge is much reduced.

The location of the salt wedge also determines its value to the ecosystem. However, it is not the distance from the sea that is critical as is sometimes suggested in literature on the Ebro. Rather, maximum production from the salt wedge occurs when it is located in a wide shallow region where algal production is not limited by either sunlight or space. It is not clear where this location should be in the Ebro, or even if maximization of production is the only goal for the salt wedge. In California, the Sacramento River salt wedge is managed to maximize production in the shallow Suisun Bay even though this is neither the natural historical location nor the nearest site to the ocean. The natural Sacramento-San Joaquin discharge is about twice that of the Ebro and the artificial maintenance of the salt wedge in Suisun Bay benefits estuarine productivity but results in a considerable loss in farm output, especially in dry years. Location of any salt wedge into deep channels, often far upstream usually reduces its ecological value. Location of the salt wedge in the ocean, as for example in the Amazon River, results in a productivity that is less than a in shallow water ecosystem.

The situation in the Ebro Delta wetlands and the analogous fringe of brackish water wetlands along the eastern Spanish Mediterranean coast has many similarities to that in the Ebro River and its estuary. High production in these Delta wetlands depends on the mixing of fresh water and ocean water in the same way as occurs in the Ebro main stem salt wedge. Nutrient and pesticide pollution reduce the dissolved oxygen in semi-stagnant pools, a situation bad for animals such as shrimp and small fish as well as the birds that feed on them. The small tidal range in the Mediterranean Sea exacerbates the anoxia in the wetland pools since tidal flushing is small compared with that in wetlands in England or The Netherlands, for example. Small aquatic animals cannot flee from the low oxygen in the wetlands and take refuge in the fully oxygenated waters of the open sea since larger ocean fauna would then eat them. Thus reversal of eutrophication and pesticide pollution in the natural areas that fringe the Ebro Delta and the entire Mediterranean wetlands chain along the east coast of Spain is essential for a sustainable ecosystem.

In many cases the restoration of the flood plain, provision of unpolluted water, reversal of eutrophication, and idealizing the salt wedge location is the impossible dream. In the case of the Ebro, the dream can become a reality if the outline proposed by the U.S. Technical Review Team for the Plan is developed further. In particular, the use of wetlands to remove the Ebro River pollution can clean up the entire river of eutrophication and other pollution as well as provide flood control, flood plain management and wildlife habitat. Details of various solutions are given the later sections, especially the Appendix.

4.1.4 Ecological effects of the diversions

The out of basin diversion of 1,050 hm³ per year of the Ebro flows by the proposed project amounts to about 6% of the historical or unimpaired discharge and 9% of today's flows (Table 1). While 1,050 hm³/y is a large amount of water, it is well within the range of historical natural changes in flows in the Ebro River. River and wetland ecology easily adapts to changes of such a small magnitude. Thus ecological degradation due to the diversion will be minor in nature and is most likely to be detrimental during dry periods. For example, the salt wedge may move to the upstream edge of the delta in dry summers. However, proposed minimum flows should prevent this and restrict upstream movement of the salt wedge to less than the historical migration range. Dry summers may cause the wetted surface in the river to decrease slightly in some wider reaches. However, the shape of the current lower river channel seems to preclude this effect for the most part. The overall degradation due to out of basin diversions will be much smaller than the effects of current water use. The current annual upstream diversions are over five times (~5,500 hm³) than the proposed diversion (~1,000 hm³).

The anticipated small amount of future damage to the Ebro due to the volume of water exported must also be put in context with the current water quality situation and the likely developments that could be made as part of the Plan as are proposed herein. Simply put, the main problems in the Ebro are not water quantity but water quality degradation. Many of the detrimental aspects of water diversion are not applicable in the Ebro and its Delta since they are in poor ecological condition. For example, water diversion could affect large fish such as the sturgeon. However, this species is now extinct in the Ebro. The current levels of nutrient pollution in the Ebro has dramatically increased eutrophication that stresses almost all biota and induces low dissolved oxygen in the reservoirs, salt wedge and wetlands pools. Water diversion will not alter the nutrients and pollutants in the water just as previous water diversions did not cause them. In other words, the detrimental effects of the diversion will be trivial compared to the problems the Ebro and its Delta face with or without the planned diversions.

Though not specified in detail, the Plan allows for a larger mitigation than would exactly compensate for the diversions. Such mitigation would allow real improvement in the Ebro River and Delta ecological situation

4.1.5 Economic Analysis

The economic analysis in the SNHP starts from the premise that a supply of 1050 hm³ per year is needed in the receiving areas. The first part of the analysis involves a cost-effectiveness exercise to select the least cost source of supply and conveyance route to

the receiving areas, with the alternative sources of supply being desalination or water transfers from the Tagus, the Duero, the Rhone and the Ebro. The Ebro was selected as the least cost source. The remainder of the economic analysis then assesses the benefits and costs of this selected alternative. Benefits are estimated for set quantities of project water allocated to urban, industrial, and agricultural uses in the receiving areas. The agricultural allotment is divided into a replacement water supply for areas currently experiencing groundwater overdraft and an allocation of water to augment supplies in areas, which are currently irrigated but are deemed to have an inadequate or unreliable water supply.

We have been informed that the economic approach used in the Plan is recommended by the EU in its Water Framework Directive, and is used in EU Cohesion Fund projects and European Regional Development Fund (ERDF) projects.¹ It is also similar to the procedures used by the U.S. Army Corps of Engineers (2000) in their Principles and Guidelines (USACOE 2000). However, many economists would suggest that a more rigorous economic approach would involve the initial selection of the project using a cost-benefit analysis.

In this review we suggest some additional economic studies that should be undertaken to refine and extend the existing analysis of the economic costs and benefits of the selected alternative. These include a study assessing conservation supply curves for urban and industrial uses of water; a study refining the existing estimates of long-run urban and industrial demand elasticities for water; studies to identify the mix of supply sources for the various groups of farmers targeted to receive imported project water and to estimate the cost differential between the cost of imported project water and the cost of other available supply sources within the receiving areas, including water obtainable through local water markets and informal exchanges, at the time when the transition to imported project water is expected to occur; based on these, a marketing study to identify farmers' demand functions for imported project water; a study to identify the marginal loss of net income in dry years for farmers in the receiving areas who currently have an unreliable water supply, taking into account the alternatives available to them and the frequency with which these years occur; a sensitivity analysis that would account for various sources of economic uncertainty; and a non-market valuation study that accounts for the positive and negative environmental impacts associated with the project. The last item is particularly important because we are proposing extensive ecological restoration that goes beyond the strict definition of mitigation for the value of the lost habitat due to the water diversions.

These proposed restoration activities are within the scope of the Plan but have not been fully defined. We recommend that a detailed analysis of the non-market economic benefits of each of the ecological restoration elements of the Plan, as suggested herein, be carried out. These ecological benefits are likely to generate an important increase in the total sustainable benefits associated with the project

¹ However, McMahon and Postle (2000) note that, in England and Wales, the Environment Agency guidance document on water resources planning requires the use of cost-benefit analysis, including monetary valuation of non-market environmental and social impacts. The Environment Agency requires that water companies base preparation of their water resources strategies on a ranking of "total water management" options, including both supply augmentation and demand management, based on average incremental social cost.

4.1.6 Water Resources

In the area of water resources we make recommendations in five areas: (1) the use of off-line dams and reservoirs for regulatory storage out of the Ebro Basin in the receiving area of the Jucar and the Segura regions. If situated correctly, these off-line dams have the significant advantage of being relatively benign from an environmental standpoint. In addition they can be developed as a pump storage hydroelectric facility and can have considerable recreation benefits such as boating and fishing. (2) The establishment of a government funded research foundation for the long-term environmental analysis of changes in the affected region. The water transfer project presents a unique opportunity to conduct an analysis of the long-term ecological and environmental impacts and changes caused by the project. (3) The analysis of the impacts of global climate change on the transfer plan. The three parameters of global climate change that possibly may have the greatest impact on Spain are changes in air temperature, sea level rise, and changes in annual runoff. The Intergovernmental Panel on Climate Change (IPCC, 2002) reports that there is a potential global air temperature change ranging from 2 to 4.2 degrees Celsius by the year 2100. Expected sea level rises is expected to be 0.2 to 0.82 meters during the same time frame. The IPCC also reports that Spain could experience a decrease in runoff from zero to 25 mm/year in the area of the Ebro transfer project by the year 2050, which is between 0-12% of the mean annual runoff of the Ebro River. The NHP analysis included a 10% reduction in the flow of the Ebro by the year 2020. (4) The uncertainty concerning additional dam construction in the Ebro River basin. There is a considerable amount of confusion concerning the number of dams to be built in the upper Ebro River basin that needs to be clarified. (5) The establishment of a metered ground water monitoring system needs to be extended to include all of the affected project area. A comprehensive ground water monitoring and control system in the effected project areas needs to be established in order to determine the location of wells, their flow rates, and their areas of influence. This monitoring system may include satellite imagery. The monitoring and control of the potential extension of irrigated areas would be an important component of this system.

4.2 OPPORTUNITIES FOR THE RESTORATION OF THE MEDITERRANEAN COASTAL REGION

The Plan could be improved by the development of a detailed blueprint for the restoration of the Ebro River, its Delta and the chain of natural brackish water wetlands along the coast of the Spanish Mediterranean. A detailed plan of ecological restoration would go a long way to allaying criticism of the Plan by environmentalists and would fulfil the EU Directorate requirement for sustainability in the Plan. For wetlands in the US and elsewhere the concept of wetland restoration has been taken further using the concept of unequal mitigation exchanges. For example, a hectare of destroyed wetland must be compensated with two, three or even more hectares of new wetland or area from a wetlands mitigation bank.

What mitigation should be offered to compensate for the water diverted? The approach taken in the Plan is to ensure that a fee on each cubic meter of water transferred will be levied and used for "environmental purposes." This is a good start. However, the current Plan leaves the details of any ecological damage assessment and ecological mitigation to be dealt with in the future within the framework of the Environmental Impact Analysis (EIA). There is a distinct contrast in the Plan between the more detailed specific analysis

of hydrology and water resources and the more general discussion of ecosystem effects and, particularly mitigation. However, in the Plan's defence, the details of the diversion engineering must be clear before environmental effects can be assessed and mitigation designed. The Plan is basically reactive to any suggestions to be made for environmental concerns rather than pro-active

In recent water projects in the United States, and California in particular, the successful approach leading to constructed projects has been decidedly proactive. Proactive purchases of valuable wildlife habitats have sometimes preceded the requests for permits for construction. Most importantly, once the outline of the proposed actions have been decided, the mitigation and proactive action must be made in coordination with environmental groups and regulatory agencies. The approach has a number of advantages but requires a moderately detailed analysis of what ecological damage is to be expected by the water diversions and what action must be made to more than compensate for the damage.

However, the Ebro River and its Delta are far from pristine systems. Any damage to be done by the diversion must be first placed in the context of what problems currently exist. Given the controversy over the Plan, a proactive course of action would be for the Plan to play a leading role in rectifying past ecological damage to the Ebro, even though the Plan has not caused all the damage. The Plan does not need to solve all of the numerous ecological problems in the Delta and downstream but is the obvious catalyst to focus attention on a complete water based recovery of the aquatic ecology in the region. In particular, the concept of an exchange or swap of water quantity (the diverted water) for improvements in water quality has some advantages. The amount of water in a system is an inflexible quantity and can only be shared so many ways. However, water quality can be improved in many ways and has a more flexible limit and the resulting environmental cleanup can be applied in various ways.

4.3 OVERALL RECOMMENDATIONS

The Plan makes no explicit detailed recommendations for actions to be taken to ensure the sustainability of ecosystems in the Ebro River or the chain of wetlands along the Spanish Mediterranean Coast. However, unlike many similar engineering projects, the Plan does have a specific funding mechanism to support ecosystem restoration. Approximately 10% of the monies generated from the water transfer will be devoted to environmental purposes in the Ebro Basin. Based on the site visits in June, we learned that these environmental actions are to be decided by various groups including the Delta Consortium. During our visit, several university scientists presented several options for restoration of the Ebro and the Mediterranean flyway wetlands but few of the presentations were by ecologists or ecological engineers. The ideas from these groups and individuals, the recommendations we make herein, and the goals already in the Plan should be coordinated in future action. For the Plan itself, details of ecological restoration and sustainability should be developed in the Plan to bring them to a comparable level with those of the hydrology and water resources sections. Although such restoration and sustainability are implicit in the Plan, the U.S Technical Review Team suggests that a detailed ecological analysis become made part of the development of the Plan.

Short term action (direct oxygenation, re-introduction of sturgeon) and medium-term solutions (restoring clean water to the natural areas, watershed eutrophication reversal

using constructed wetlands, raising the delta mean elevation, and restoration of some riparian features) should be developed as the Plan's first definite improvement to be made in the Ebro River drainage including the Delta. The short-term solutions can be accomplished in 2-5 years; the medium term improvements can be implemented in 3-10 years. Long-term solutions (> 10 years) include restoration of sediment transport down the river, more complete clean up of nutrients and toxicants in the watershed, restoration of the riparian corridor (size to be determined). The justification for the minimum flow of 100 m³/s in the Ebro River needs further development in relation to the ecology of the salt wedge.

Detailed development of the feasibility of off-line storage in the lower reaches of the Jucar-Segura systems is needed. Many storage reservoirs have been constructed in California in conjunction with the large-scale water transfers. However, no storage reservoir has been constructed on-line (i. e. on a live river) in California since 1970. Off-line reservoirs are usually more expensive than simply damming a river valley. However, there are usually many sites that have a small watershed and are essentially dry valleys that can be used for downstream off-line storage. Special emphasis should be given to the criteria of reduction of environmental impacts and encouraging public water-based recreation when planning the new reservoir locations.

An economic analysis of the value of the proposed ecosystem restoration should be further developed. The analysis should include sufficient detail to provide information for the value of individual restorations (e.g. removing anoxia from the salt wedge, anoxia removal from the Delta wetlands or the rest of the Mediterranean flyway wetlands, the restoration of the extinct sturgeon, enhancement of the very rare *Margaritifera* clam, or provision of wetlands along the main stem). On the demand side a development of a marketing plan for the water should be integrated into the current legal framework on groundwater over drafting.

We recommend that a research institute, similar to those set up on the Colorado River in the US (annual discharge almost identical to the Ebro) be considered to provide a more integrated and focused base for the ecological restorations needed to offset the water diversions. The proposed research study would first establish a baseline of environmental indicators. Of particular importance is the further development of monitoring and recording of current ground water levels in unconfined aquifers, the current area and extent of sea water intrusion into coastal aquifers, the flora and fauna along the route of the proposed canal and surrounding environs, the current ecological condition of the coastal wetlands along the route of the canal, and the current ecological condition of the Ebro River Delta. It is also recommend that the Plan develop a comprehensive environmental monitoring plan, which will establish the current levels of ground water in the Segura and the Jucar basins. Furthermore, monitoring of the wells via a metering system should be investigated. An enforcement policy and or a monetary penalty should be developed further to ensure the stoppage of the continued pumping of water from over-exploited aquifers.

4.4 CONCLUSION

Our main recommendation is to further develop the Plan to incorporate more detailed and timely ecological design for the Ebro River and Delta, coastal wetland restorations,

off-line regulatory storages, and long-term research studies. We believe that if our recommendations are carried out, the ecosystem will be greatly enhanced.

To further this goal we suggest a working title for the development of the plan that more fully reflects the Plan's intentions. For example a title could be, "A Restoration and Enhancement Plan for Sustainable Ecology and Agriculture for the Spanish Mediterranean". The developed Plan should focus on providing "win-win" solutions to the wide range of water-related problems that currently exist in the Lower Ebro River, the Ebro Delta, the coastal wetland chain, and depleted groundwater. Such a title would be more supportive of the needs of the ecological community while at the same time ensuring that the civil engineering part of the Plan was carried out to supply both ecosystem and agricultural needs.

5.0 APPENDICES: FINDINGS & RECOMMENDATIONS

APPENDIX 5A: HYDROLOGY (After our early suggestions, various groups in Spain completed many of the studies)

BY: IGNACIO RODRIGUEZITURBE assisted by ALEX HORNE

FINDINGS

The plan is based in a hydrologic study, which encompasses 3 main different aspects logically related to each other (Plan Hidrológico Nacional-Análisis de Sistemas de Recursos Hidráulicos, Septiembre 2000. Referred from now on as PHN-ARH,2000):

- 1- A detailed hydrologic study of the characteristics of the virgin stream flow series in the lower Ebro River.
- 2- Incorporation of the demands of different type in a horizon of 20 years -internal to the basin- to study through a hydrologic model the expected flows in the lower Ebro after satisfying these requirements.
- 3- A study of the flows the Ebro would carry into the sea and the possible transfers outside the basin that from a hydrological viewpoint could take place with acceptable reliability in the exports.

We now proceed to discuss the main findings in each of the above main aspects.

1. Estimation of Virgin Flows in the Lower Ebro River.

The Ebro river basin has near 85,000 km² and a river course length of about 910 km with a present mean annual flow in its lowest reach of 11,500 hm³/yr (PHN-ARH, 2000, see also Table 1). Its water is intensively used throughout the basin and a study of the type we are concerned with needs as a fundamental piece a pseudohistorical record of virgin flows. These are those discharges at the sites of interest, which would have taken place if the river basin had remained in its natural condition (e.g., without any human interventions throughout the years). It is from this series of virgin flows where it is possible to carry on studies that will incorporate the internal demands-inside the basin-at different planning horizons and then continue to investigate the possibilities of exportation of water outside the basin with different levels of reliability associated to different export volumes and regulating works. The subject of the virgin flows in the lower Ebro has been one of intense controversy throughout the years. The analysis is centered in the record at the most downstream station called E-27 Rio Ebro en Tortosa or simply Tortosa. This station has a record since the beginning of the century although there are numerous gaps in the information in the first half of the records. The data at Tortosa presents a significant decreasing term whose causal origin is important establish for purposes of the study. The hydrologic study suspects that the data between 1910 and 1940 in addition to its numerous gaps is not reliable. A comparison of this part of the record with those existing at the station E-11 Rio Ebro in Zaragoza and E-02 Rio Ebro in Castejon, tend to confirm the suspect character of the record at Tortosa for years before 1940 and its reliability for the period after 1940. Any missing data from 1940 on was then filled in via regression analyses with other stations on the Ebro basin near Tortosa. In this manner a series of historical flows was estimated for the period 1940/1941 to 1995/1996 (PHN-ARH, 2000).

The decreasing trend in the period 1940-1996 was studied in detail to investigate if its origin can be explained in basis to the corresponding historical increases in the consumption of water throughout the basin, upstream of Tortosa, or if -on the contrary- other explanations related to a decrease in precipitation are more satisfactory. Thus taking into account the evolution of the storage volumes throughout the years, the hydrologic study carries on a balance to estimate from the historical record 1940-1995 a pseudohistorical sequence of virgin-or natural-flows for the Ebro at Tortosa. This series agree quite well with other virgin sequences for Tortosa estimated with different methodologies. Moreover, the series of virgin flows, combined with the record at Tortosa and the storage fluctuations allows an estimation of water consumption in the basin, which agrees quite well with a direct calculation of the consumption. In fact, the net water consumption in the Ebro basin is stable and near 3,300 hm³/yr for the period 1940-1950, it increases up to 5,000 hm³/yr from 1950 to 1970 and then it continues to increase at a much slower pace reaching near 5,500 hm³/yr at the present time (Table 1).

The series of pseudohistorical virgin flows at Tortosa for 1940-1996 has an annual mean of 17,265 hm³/yr with a range of variation that goes from 8,000 hm³/yr in the driest years up to 30,000 hm³/yr in the wettest years. Very importantly, this series does not show any significant trends (PHN-ARH, 2000). This conclusion is quite important and it is backed by the coherent agreement of the estimated virgin flows, the historical record, the demands and the consumptions in the basin. Thus the decreasing trend in the historical record is explained through the increase in the water use in the basin and especially through the increment that has taken place in irrigation. The hydrologic study proceeds to corroborate this conclusion through the comparison of the series of virgin flows at Tortosa with the recorded mean annual rainfall over the whole Ebro river basin. Both series show quite good agreement in their temporal evolution and further statistical tests reject the possible presence of a decreasing trend.

2 Estimation of flows in the Lower Ebro after demands are satisfied in the future

The hydrologic study estimates the flows that may be available at Tortosa after covering all the internal water demands the Ebro basin may have in a planning horizon of 20 years in the future. Thus, in the case of irrigation demands, the present irrigated area of 783,948 ha would increase up to 1,271,306 ha in 20 years. When observing the past evolution of the area under irrigation, the study shows that the estimated value at 20 years is considerable higher than the value one would obtain from extrapolation from the historical data. Thus the value of 1,271,306 ha is taken as the figure that will comply with all the plans that exist among the different regions inside the basin for this horizon.

In the case of other demands, there were identified a number of units that merit a differential non-aggregated treatment in terms of their importance (e.g., Pamplona, Zaragoza). Population and industrial demands were estimated and considered in the analyses with projections to a horizon of 20 years. In addition to irrigation, population and industrial demands, the hydrologic study also considers the requirements for cooling of nuclear and thermal plants inside the Ebro basin. There exist external transfers to the regions of Catalonia and Norte III, which were also accounted for.

The return flows were estimated as 80% for the case of the urban and industrial demands and as 25% for the case of irrigation flows. The total estimated future

consumptive demand is 13,767 hm³/yr, of which 8,847 hm³/yr is spent and 4,920 hm³/yr return to the system. Particularly important is the establishment of a required minimum flow of 100 m³/s at the mouth of the Ebro river (3,154 hm³/yr or 263 hm³/month; PHN-ARH,2000). This value is equivalent to 19% of the mean annual virgin - e.g., natural-flow at Tortosa. With the above demands the hydrologic study then proceeds to incorporate into the analysis the main reservoirs contemplated for construction during the next 20 years. These reservoirs in addition of the basic conductions needed in the scheme provide a basic system of hydrologic exploitation of the Ebro river basin whose operation is optimized to yield the resulting annual and monthly stream flows at Tortosa when the system hydrologic input is the series of monthly virgin flows generated at all the nodes of the scheme (towards this the study implemented a rainfall-runoff model at the monthly scale level calibrated at different parts of the basin).

The above analysis allows the estimation of the stream flows in the lower Ebro for a series of 55 years when the prescribed demands have been met and the hydrologic conditions were those of the period 1940-1995. The mean annual flow at the mouth of the Ebro is thus estimated in 8,370 hm³/yr. Subtracting from this value the minimum flow requirement of 3,154 hm³/yr the hydrologic study arrives to a flow value of 5,200 hm³/yr, which is considered as of possible use for external transfer purposes.

The results from the simulation indicate that at the annual level it is possible to maintain the mean annual flow at the mouth above the minimum requirement of 3,154 hm³/yr (PHN-ARH, 2000). At the monthly level the situation is not totally clear and there seem to exist a very reduced number of occasions where the minimum monthly flow of 263 hm³/month was not met.

3- Available Flows Above Requirements.

The value of 5,200 hm³/yr, as estimated flow at the mouth after requirements are met, is subject to critical seasonal variations and it is mainly concentrated in some months of the year. Thus, this flow is in fact reduced to the minimum requirement in the period of June through September (PHN-ARH, 2000). The months that contribute the highest yield are those from December to May, which embody 75% of the annual flow and 90% of what is called exceeding discharges (above requirements).

The above-pronounced seasonal behavior has important practical implications. Thus, it is absolutely necessary to increase the regulating storage in order to contemplate any possible exports and also to exercise a reliable control of the existence of an appropriate minimum flow in the lowest reach of the Ebro.

The hydrologic study evaluates the reliability of the supply of an external demand (export) from the 5,200 hm³/yr for different values of the demand and different storage capacities allocated towards this purpose. The analysis is made assuming a continuous demand during the 8 months of October through May and zero demand in the months June through September. The study makes clear the absolute need of additional storage to contemplate any use of the discharges at the mouth of the Ebro. As reference value it is estimated that with storage at the origin of 1,000 hm³ it could be possible to transfer 1,000 hm³/yr with an intake of 1,100 and 1,300 hm³/yr with an intake of 1,500 (PHN-ARH, 2000).

It is interesting to remark that in the hydrologic series used in the study (equivalent to hydrologic conditions in the period 1940-1995) there exist a period of 4 years, 1988-1991, which leads to critical conditions where the flow at the mouth of the Ebro would be just about the annual minimum required of 3,154 hm³/yr (without any exports being implemented). This points out the importance of multi-annual regulating capacity for not only contemplating the possibility of exports but also to maintain the minimum required ecological flow with an appropriate degree of reliability.

In the lower part of the Ebro exist two reservoirs whose purpose is hydroelectric generation. These reservoirs are Mequinenza and Ribarroja with useful total storages of 1,330 hm³ and 135 hm³, respectively. It appears that if the use of these storages-or part of them depending on the volumes to export- is primarily changed towards satisfying transfer requirements, it could be possible strictly from a hydrologic view point to implement such transfers. Obviously, it could also be possible-in principle-to increase storage towards regulation in the reception end of the transfer.

The hydrologic study carries out a preliminary study of the impacts on the flows of the lower Ebro, with the full demands of a planning horizon of 20 years, of a general decrease in the natural flows of 5% and 10%. This is referred to in the study as impact of a possible effect due to climatic changes. The conclusion is that under this hypothesis there is no appreciable change in the general results.

4. Effect of dams and daily flow variations due to power generation and pollution generation downstream

The flow variations in the river due to hydropower peaking generation affect fish and benthic wildlife. Toxic hydrogen sulfide is probably being generated in the deep waters of the two large eutrophic hydropower reservoirs.

Reservoirs used for hydropower normally have peak flows in the afternoon and low flows overnight. This regime can be compared with normal summer flows that would be almost constant over the day. Variation in flow velocity in rivers does not have a large effect on stream organisms and they can adapt to any flow regime. However, flow variations that expose sediments or gravels have a serious detrimental effect. Thus any flows specified in the Plan should not expose the streambed, but could expose some sides of the riverbank. As mentioned before flow variation that does not expose the riverbed is likely to be less important than the quality of the water flowing from the anoxic hypolimnion of the reservoir.

To the extent that flow provides dissolved oxygen to the gravels, a minimum flow is important. However, the water must be free of hydrogen sulfide and well oxygenated before increased flow becomes a benefit to the river below the reservoirs.

Of the immediate problems facing the Ebro River system anoxia (lack of dissolved oxygen) is the most serious and most easily solved. The cause of low oxygen is not primarily flow-related but due to eutrophication caused by increased nutrient loads to the entire Ebro River. Overall reduction of nutrients on a watershed or basin-wide scale is an area of much current interest in the US in the Total Daily Maximum Load (TMDL) program. The TMDL program accounts for natural, point source (domestic and industrial effluents), and non-point or diffuse pollution (city storm and other runoff and agricultural

runoff). Reducing nutrients from sewage and agriculture is a medium-term process but could, with general support, reduce nitrate and phosphate within a decade. This has occurred in California on one occasion but most TMDL projects have failed to take account of the full range of treatment options, such as treatment wetlands, and cleanups are taking a long time to produce results.

Thus, short-term methods are needed that will economically solve the problem of anoxia until longer-term solutions become effective. Artificial oxygenation (or aeration) is the only concept that satisfies these needs. There are four sites in the Ebro River where oxygenation is needed:

- The delta salt wedge
- Lagoons in the natural areas
- The lower Ebro
- The hydropower reservoirs

HYDROLOGY: RECOMMENDATIONS

The recommendations in the area of hydrology will follow the 3 main different aspects, which were the subject of the hydrologic findings as discussed above.

5- Recommendations Related to the Establishment of a Series of Virgin Flows.

The series of pseudohistorical virgin flows at Tortosa for 1940 through 1996 and the tests this series underwent in the hydrologic study are a most important piece of information. We recommend that this series will be used in so as to extract the maximum possible information it contains and at the same time facilitate the study of the impact of hydrologic uncertainties in the whole project.

Presently, the hydrologic study uses the pseudohistorical series of virgin flows described above as the basis of all the studies that are carried out. It is recommended that such a series be further used for estimation of the hydrologic parameters characterizing the flows at the monthly and annual level. Thus from the series obtained above the following parameters are to be estimated for every month and at the annual temporal scale: mean values, variances, and autocorrelation coefficients. These represent the statistical characterization of the stream flow sequence at Tortosa under natural conditions.

The parameters obtained above are then to be the basis of a synthetic generation of stream flows statistically undistinguishable of the virgin series in the period 1940-1995, both at the monthly and at the annual scales. The generated stream flows will form a long series which carried out throughout many years - e.g., 1000 years- will surely contain episodes of flows that will test the system under most stringent and critical conditions that those contained in the 55 pseudohistorical years. This procedure will also allow for a more appropriate approach to estimating the probabilities of failures under different conditions of demands and transfer scenarios.

It is recommended that the generated series of stream flow be those to be used in testing different schemes throughout the study. As described before the different alternatives will be subject to a much larger range of possible hydrologic scenarios

resulting from the set of statistical characteristics determined by the hydrologic study for the virgin annual and monthly flows of the lower Ebro river.

Furthermore it is also recommended to study the uncertainty of the statistical characterization that is derived from the pseudohistorical virgin flows in the period 1940-1995. Thus, the statistical parameters described before may be changed to generate similar long-term series of synthetic stream flows-at monthly and annual level-which represent scenarios more pessimistic with respect to the structure of the flows. Possible situations to be considered are those in which the coefficient of variations at the annual and monthly level are larger than those observed in the pseudohistorical natural flows of the period 1940-1995. This could happen either because of an increase in the variance of the flows - e.g., larger range of fluctuations-or because a decrease of the mean discharges, or a combination of both. The synthetic stream flow series generated with these set of statistical parameters would represent more pessimistic conditions-in a statistical sense- than those obtained in the original synthetic generation recommended before.

After our early suggestions concerning the hydrologic analysis, various groups in Spain completed many of the studies recommended above. For example, a new study (Cabezas,F.,2002) was carried out which generated synthetic streamflows using a temporal/spatial desaggregation scheme. One hundred series of 60 years were generated to quantify, in probabilistic terms, the storages needed in order to achieve the planned transfers. These analyses reach the conclusion that indeed there exists sufficient storage capacity in the lower Ebro River basin to attend those needs.

6. Recommendations Related to the Estimation of Flows in the Lower Ebro after Future Demands are Satisfied.

The planning horizon used in the study of demands was of 20 years. All demands of different types contained in the plans of the regions of the Ebro River were included in the calculations. A comment in this aspect is that although a horizon of 20 years seems short for a project of this magnitude, the demand values obtained from the simple aggregation of the different regional plans is considerably higher of what could be expected in 20 years from the extrapolation of the temporal evolution of demands in the historical data, specially in what concerns to irrigation demands (PHN-ARH, 000, Figure 81). The analysis of demands and their uncertainties is an important topic that merits additional study.

A very important aspect of this part of the hydrologic study is the establishment of a value of 100 m³/s (3,154 hm³/yr; 263 hm³/month) as the minimum flow requirement at the mouth of the Ebro River. Two aspects seem important to remark in this topic:

1. The minimum flow value of 100 m³/s needs to be validated with ecological considerations, further development is needed as discussed in the ecological section.
2. A detailed statistical study should be undertaken of the minimum flows to be expected in the lower Ebro River. A common approach used in the US for the analysis of low flows is the determination of the 10-year frequency of the annual seven-day low flow.

Both aspects above are closely related. Thus, the probabilistic structure of minimum cumulative daily flows should be studied in detail to establish its relation to any ecological impact. As an example one could think of a target as minimum flow based on trying to maximize stream wetted surface below the initial bank line with the goal of optimising invertebrate populations and thus fish food. Higher occasional minimum flows might also be established to sweep gravel clean of silt prior to fish spawning. Important questions to be addressed include how different are expected to be the probabilistic structure of cumulative daily flows in a pseudohistorical virgin condition, in the present state and under different scenarios of storage and export transfers with the future demands with which the system is suppose to deal.

Detailed development of the feasibility of downstream, our of basin off-line storage in the lower reaches of the Jucar-Segura system and in the Barcelona area would assist the Plan by providing more flexibility. Most recent water developments in California (about \$3 billion in the last 5 years) have been off-line storage to allow for flexibility on droughts and also for earthquake and water quality protection. Emphasis should be given to the development of reduction of environmental impacts and enhancement of existing or restored wetlands when determining the possible size and location of downstream off-line water storage reservoirs. It is recommended that all estimations of flows in the Ebro be made using the synthetic stream flow series described in point 5.2.1 above. The analysis could then be developed to include different scenarios of possible parameters characterizing the statistical structure of the pseudo-historical series of virgin flows.

We note that various groups in Spain have already completed many of these suggestions following our initial comments. For example, a recent study (Cabezas ,F.,2002) was carried out to investigate the probabilistic structure of the minimum flows of the lower Ebro River at Tortosa. Different analyses were performed for a series of virgin flows for the period 1951-2002 (the data before 1951 was not considered reliable). The probability distribution was estimated for the minimum accumulated discharges for periods of 7 days, 30 days and 120 days. These analyses show that from a strictly hydrologic view point the minimum daily discharge of 100 m³/s for the Ebro River as used in the plan is adequate when compared to the time series of low flow discharges. The ecological rational of a minimum value for streamflows for the lower Ebro River will be discussed in the ecological section of this report.

7. Recommendations Related to the Study of Available Flows Above Requirements.

It is recommended that the operation of the system be simulated including synthetic series of large duration and for different possible statistical sets of parameters, which would address the concerns of the uncertainties present in the available data, and the corresponding series of virgin flows. Special attention should be given in this aspect to the critical seasonal variations as well as to the interannual occurrence of critical periods. These aspects are discussed in the hydrologic study and were considered when carrying out the analysis at the monthly and annual levels with the pseudohistorical series 1940-1995.

Special attention could now be placed in the reliability of the transfers and the minimum flow requirements when carrying out the analysis through synthetic series of long duration. This will allow a more reliable estimation of the probabilities describing such variables for different values of storages at the origin and different intake capacities.

Moreover different scenarios of statistical parameters - e.g., increase in the coefficient of variations-will help to clarify issues like the impact of the historical period selected as well as the impact that statistical deviations from this period may have in the project.

8. Recommendation on effect of dams and daily flow variations due to power generation and pollution generation downstream

Develop the Plan to provide details of the effects of variable flow, especially in the afternoon. Ramp the flows to allow species to migrate to the center of the channel. Ensure minimum flow to cover the entire riverbed wetted surface. Develop the Plan to provide oxygenation in the hypolimnion of these reservoirs during the later part of the summer stratification period when oxygen is depleted by algal decomposition.

APPENDIX 5B: ECOLOGY

BY: ALEX HORNE AND JAMES ROTH

FINDINGS

1.0 THE SINKING EBRO DELTA

1.1 Findings: the sinking Ebro Delta

The Ebro Delta elevation is not sustainable. The land is slowly sinking and encroaching seawater will destroy the brackish water wetlands and all agriculture.

The Ebro Delta was created artificially about 500 years ago by a steady but unsustainable supply of sand from catastrophic erosion in the upper drainage. Deforestation for shipbuilding and agriculture in the Ebro Basin was the reason for the erosion. No sediment is now being added to the Delta due to dam construction and reforestation. One way of looking at sustainability would be to allow the delta to disappear since it was not sustainable in the first place. However, due to losses elsewhere, the Ebro Delta now has such irreplaceable wildlife potential that its continuance should be a main plank in any Ebro ecological plan.

The essence of the concern in the Ebro Delta is that the delta will cease to exist in about 100 years due to a combination of sinking land and rising sea level. The land is slowly subsiding at a rate of about 1 mm/y while the sea is rising at about 2-3 mm/y. Unfortunately, before the land is totally flooded, ecological and agricultural damage will occur in the lower or more vulnerable areas. Agricultural land is more sensitive to marine flooding since the salt must be washed from the soil after each flooding. In the main California delta, organic soils are oxidizing and sinking. Some farmland in California's Sacramento River Delta has been abandoned and remains permanently flooded, albeit with fresh water.

The Plan needs to be pro-active in encouraging the possible methods to add elevation to the Delta farmland and wildlife (natural) areas. All conceivable methods involve manipulation of water in the region.

1.2 Recommendations: the sinking Ebro Delta

For a sustainable future, the soils of the Ebro Delta must be replenished. There are two options. First, develop the Plan to study and implement addition of *inorganic* sediment now held upstream behind dams by direct river transfer or indirect methods (pipelines, rail etc.). Second, present details and plans to create new *organic* sediment on site in a sustainable fashion using the peat formed under new permanent wetlands in the Delta.

The Ebro Delta will experience increasing flooding problems over the next 100 years due to the sinking of the land and the rising of the sea level. After 100 years, the area will probably not be suitable for agriculture and the sea will reclaim many of the natural areas. The problem is common to many coastal regions of the world, although since the Ebro Delta is composed of recently deposited sand, the situation is not as dire as other areas. In the Sacramento-San Joaquin Delta in California, for example, the organic soil surface is sinking at a rate of about 6 cm per year and is already well below sea level.

Severe flooding has occurred and future flooding and loss of all agriculture, roads, and water pipelines is certain.

For a sustainable future, the soils of the Ebro Delta must be replenished. There are two options:

- Add inorganic sediment now held upstream behind dams by direct river transfer or indirect methods (pipelines, rail etc.).
- Create new organic sediment on site using permanent wetlands in the Delta.

1.2.1 Addition of upstream inorganic sediments

This option has the advantage of being the method by which most of the delta was created five hundred years ago. The main problems are:

- How to move the sediments, now held behind the two large upstream reservoirs
- How to detoxify any pollutants in the upstream sediments
- How to spread the sediments on the delta without destroying the current farmlands and natural areas

Sediment transfer by mechanical means. The amount of sediment needed to raise the delta by one meter would be 320 million cubic meters ($320 \times 10^6 \text{ m}^3$). Even to raise 25% of the delta by 10 cm would require 8 million cubic meters of sediment. Using conventional civil engineering techniques, the sediments would have to be dredged from an operating reservoir or excavated from a drained one and then transported by truck, rail or fluidized pipeline to the site. The approximate cost of moving such an amount of sediment would be over 100 million euros [$8 \times 10^6 \text{ m}^3$ sediment @ $\text{€ } 5/\text{m}^3$ (dredging) + $8 \times 10^6 \text{ m}^3$ sediment @ $\text{€ } 10/\text{m}^3$ (truck/train)]. Costs for sediment effects in the reservoir, power losses if the reservoir were drained, road damage and/or partial rail construction and loss of agricultural production and natural wetlands during the sediment spreading operation would considerably add to the cost, perhaps doubling the total. Costs to increase the Delta by 50 cm thus could reach $\text{€ } 1$ billion.

Sediment transfer by restoration of river transport. Restoring the Ebro River's sediment load would be a natural method of moving upstream sediments downstream using the store of material behind large and small dams. This method is attractive because transport costs are small and the method has many sustainable, natural features. Restoration of the natural sediment transport has many additional beneficial features including the replenishment of the gravels needed for fish reproduction in the lower Ebro River. In addition, the gradual and not so gradual decreases in operating volume of the reservoirs could be prevented leading to a sustainable reservoir system from a water storage viewpoint.

Restoration of the natural sediment transport in the Ebro River is not possible when reservoirs function as storage facilities. During the short period when sediment is transported via the river the reservoirs would need to be drained. Controlled passage of upstream discharges then mine the sediment in the old thalweg and pass it down the river. Depending on the amount of sediment needed, the number of reservoirs involved would be few or many. In principle, short sections of the river could be utilized moving stored sediment between dams high in the watershed all the way to the delta in a

gradual process using only two dams (one drained and one for upstream flushing releases).

Probable sediment pollution in Ebro Reservoirs. We have seen some preliminary data concerning some pollutants in the sediments of one of the large hydropower reservoirs. Some heavy metals and organic pollutants were present as might be expected for reservoirs downstream of major cities with many years of partially treated industrial and domestic sewage and agricultural runoff. However, many of these legacy pollutants may be inactive or only slightly bioactive and will cover soils that are currently polluted with agricultural pesticides. A study is needed of the amount and kind of pollutants that are present in the sediments of the main Ebro River reservoirs (some data is already available). In addition, a measure of the likely releases of any toxic material is also needed and can be measured in sediments using various elution and bioassay techniques.

Sediment detoxification. If the sediments containing pollutants is transferred in an organized fashion and placed on the low points of the land it would be possible to treat most pollutants in situ by additions of the appropriate materials during deposition. Expected materials would include organic matter such as green waste, sawdust or similar material. A study should be made to determine the feasibility of this pollutant restoration technique since it is the key to restoring the sediment flow in the entire river in a sustainable and non-polluting fashion.

1.2.2 Raising the level of the Ebro River Delta by production of organic sediments in situ

Wetlands. An alternative to supplying inorganic sediments similar to those that comprise today's delta sediments is to produce organic sediments in situ. Wetlands have a known ability to produce organic matter by photosynthesis and up to 1 cm/y can be produced under some circumstances. However, the wetlands must be designed and maintained correctly or the organic matter produced will be lost. Primarily the wetlands must be permanently flooded during the years when increase in land level is needed. If the wetland is dried out, especially in summer, the organic matter produced will be oxidized to carbon dioxide by bacterial and fungal respiration and no net accumulation will occur.

Global carbon credits. Raising the land level for the Ebro Delta by wetlands production is a sustainable method since energy comes from the sun via photosynthesis and the carbon dioxide from the air. The method can be used to obtain atmospheric carbon dioxide credits in global warming pollutant trading.

Farming compatibility. The design of wetlands used to increase the level of the delta would be compatible with the sustainable continuation of some rice or other delta farming. After the suitable increase in elevation has occurred (for example 25 cm in 25 years), the land could be returned to farming and another low area of farmland selected for elevating. Alternatively, the wetlands could remain as valuable wildlife habitat. However, if farming were selected, the organic soil would gradually decline and in about 50 years the land would have to be rotated through wetlands again for a sustained land surface while farming would move to the next wetland region that had been growing and accumulating sediment.

Methods. The selection of the correct wetland plants is as important as keeping the land wet year-round. Appropriate plants could include *Scirpus*, *Phragmites* and *Typha* but it is important that these plants be assessed for their ability to accumulate lignin-based carbon. For example, we have found in California that *Typha* contains a surprising amount of bioavailable, non-lignin carbon. Although this bioavailable-C makes *Typha* an excellent wetland plant for denitrification of nitrate and sequestration of heavy metals, it renders it less good for sediment biomass accumulation. The opposite is true for *Scirpus*.

2.0 Sensitive aquatic species in the Lower Ebro River and Delta

2.1 Findings: sensitive aquatic species

There are sensitive aquatic species in the Lower Ebro River and its delta. One species, the pearl mussel, *Margaritifera*, is very rare (thought extinct in all Europe until recently). Another species, the sturgeon is now extinct in the Ebro. Other species are reduced in abundance and range.

Several aquatic species have become extinct or are threatened in the Ebro River and its Delta. However, for some of these species, there is no discharge-related reason why this should be so based on volumes of water potentially available. Examples of extinct or rare organisms are the valuable sturgeon fish (extinct), the endangered *Margaritifera auricularia* clam and the associated freshwater blenny fish. Special provisions can be made for these species, primarily elimination of anoxia, provision of clean gravel spawning areas and elimination of spikes of pesticide.

However, the preservation of a handful of rare species in a kind of outdoor zoo is contrary to sustainability. Long-term survival requires that a more complete community of common and rare species be maintained, if only because the more common species are often the food supply for the rare species.

For most aquatic species the most important environmental features are an abundance of well-oxygenated, fairly clean water provided with the correct hydroperiod. Many of the requirements can be provided as water deliveries as part of the developed Plan. For example, the correct hydroperiod is simply a matter of matching the releases from the upstream dams to the needed flushing of organic silt from the gravel and minimum ecological flows required. The maintenance of gravel beds themselves for spawning or habitat is somewhat more complex since the main supply of sediment from upstream has been prevented by dam construction. Sweeping silt from gravel is accomplished in nature by higher water flows but new gravel is normally added from upstream during floods.

The provision of well-oxygenated water is the key to success for aquatic biota since with ample dissolved oxygen the toxicity of several common pollutants such as ammonia is reduced. The chances of lowering the concentrations of many pollutants in the lower Ebro River are poor over the next decade or more since upstream industry, agriculture, and domestic sources of pollutants will remain important. In addition, there is a reservoir of legacy sediment pollution of unknown concentration. The methods of oxygenation for the river are discussed in the recommendations section.

2.2 Recommendations: Sensitive aquatic species

Develop the Plan to make the sustainable restoration of the pearl mussel and the sturgeon a centerpiece of the Plan. Develop the Plan's 100 m³/s minimum flow to ensure provision of habitat and water flow regimes for these species. Include water flows to provide of deep clean oxygenated gravel for sturgeon spawning in spring, enhancement of submerged aquatic vegetation of the blenny fish (alternate host for the young mussels) in spring-summer.

2.2.1 Restoration of rare aquatic species in the Ebro River.

The now extinct Ebro River sturgeon and the rare *Margaritifera* clam and the blenny are appropriate key species to become part of the Plan. A few other species could be included but the environmental conditions required by these three forms should improve the habitat for all Ebro River species. The Plan should explain how its role of in the future manipulation water flows, sediments and oxygenation would restore or sustain and expand existing populations. Experience in California shows that action to enhance endangered species plays a major role in how and when water is transferred, even long after the construction project is completed. The concern is most directly felt by water transfer agencies with migratory anadromous fishes (breed in rivers, live in ocean) such as the sturgeon. If the Plan was to become a major player in the restoration and sustenance of a very large flagship species such as the sturgeon, many other environmental concerns would diminish.

Sturgeon. Experience in the Great Lakes of America, especially Lake Michigan, has shown that it is possible to breed and introduce large number of small sturgeon so that a critical mass is reached. The Plan, if appropriately developed, would indicate how the ecological condition of the Ebro River would be improved to allow the sustainable natural reproduction of the sturgeon, once new populations have been introduced from other European Rivers. The anadromous habitat of the sturgeon, where it breeds in rivers but spends much of its time in the sea, probably allowed some interchanges of populations in the past between various European Rivers. Primary concerns are prevention of anoxia in the river, provision of well-oxygenated gravel beds for spawning, and removal of barriers to upstream migration. Fish ladders would certainly work around the small Flix dam but hydraulic conditions around the dam should be assessed to find the best location for fish ladder(s). It is not clear how successful fish ladders would be for the two large hydropower dams but the possibilities of fish ladders, round the dam trucking and other methods should be investigated. In addition, methods are needed to ensure the safe the downstream passage of the young sturgeon, threats from turbine blades in the hydropower plants and similar mechanical problems

Sturgeon are not only very large fish, up to 100kg and a length of 4m, but are long-lived so can survive periods of drought or even occasional pollution events in the rivers if they are at sea at the time. However, in most of the world, over-fishing, destruction or pollution of breeding gravels, and blockage of upstream migration had devastated sturgeon populations. The declines continue, especially in the Volga and Caspian Sea, despite the high economical value of sturgeon eggs (caviar). The Plan could make a valuable contribution by reversing this trend. Finally, the expansion of the rare *Margaritifera* clam requires a fish host to transport its larvae upstream. Some evidence points to the sturgeon as the main host fish for the clam.

Margaritifera clams. The clam *Margaritifera auricularia* is a large (to 20 cm long) freshwater unionoid mussel, was once common in European rivers. It was once thought to be totally extinct in all rivers but recently a few small populations were found, primarily in the Ebro Drainage. This species is now considered to be one of the most threatened invertebrate species in the world. It is now known from a population estimated at 2000 individuals in the Imperial Canal of Aragon, a channel created in the 1780's near Zaragoza, which parallels and is connected to the Ebro River. It also occurs in the nearby (middle) section of the Ebro itself, although little is known about its abundance. In the lower section of the Ebro the species is also known to persist, but again has been inadequately sampled. Estimates of the Ebro river population have varied between several thousand and "small groups separate from one another."

Most importantly, no young clams were found in the Imperial Canal, which means that the adults are not reproducing successfully. Lack of reproduction can be due to several factors but one is certainly that sturgeon, a probable host for the larvae of river clams, are not present. For river organisms that are not mobile as adults, some method is needed to carry the young clams upstream since the free-swimming young are too tiny to swim against the current and washed downstream. In the case of river clams, the usual method is for the clam larvae to attach to a fish for a while as a parasite. Later on the larvae drop off to the sediments. The small blenny fish (see below) is also a host for the young clams. The Plan could be modified to work towards the increase in sustainable habitat for *Margaritifera*.

Margaritifera requires sediment of pebbles, followed by gravel and sand with only a small fraction of silt. This is typical of streams with good flow at times to clean out silt from the sediments. It is not known if the Imperial Canal has the most suitable sediments. Adults are capable of burrowing into the sediment a few meters when the water level is low. Clean, well-oxygenated sediment is required for juveniles, and they cannot survive if the substratum becomes clogged with silt. Little is known about the requirements of the very early stages. Anecdotal observations by fishermen indicate that mussels are (or were) abundant immediately downstream of small waterfalls (possibly due to lower silt or more food). The minimum flow regimes specified in the Plan should be examined to determine if there is some other need than 100 m³/s or some variation in flow that would be more suitable.

Blenny fish. The river blenny, *Blennius fluviatilis* (also known as *Salaria fluviatilis*) is a freshwater member a mostly marine family of fishes. The freshwater blenny is a small (7 cm maximum length) species found among sub-aquatic vegetation in the river, main canals, and sporadically in the coastal lagoons during freshwater periods. It is endangered, threatened by loss of habitat and the introduction of exotic species. Its significance in the Ebro system is further enhanced by the recent laboratory demonstration that it is a host to the glochidia of the rare clam *Margaritifera auricularia*, the only known species in the Ebro which has been shown to do so. The now extinct sturgeon was probably a main host for the clam. The blenny requires submerged weedy areas for feeding, protection from predators, and for reproduction. The Plan should ensure that such habitat is present and preserved or even expanded in areas where the *Margaritifera* clam is present or could be present in the future.

3.0 Chain of brackish water wetlands along the Spanish Mediterranean Coast

3.1 Findings: Coastal brackish water coastal wetlands

The ecologically vital chain of brackish water coastal wetlands is threatened by pollution from agricultural return water supplies and possible incorrect hydroperiods.

There is a chain of coastal wetlands and brackish water lagoons that begins at the Ebro Delta but continues all the way to the terminus of the Plan water delivery area. The wetland chain is vital for bird movement along this section of the Mediterranean Sea. The wetlands are currently not in sustainable condition due to eutrophication and toxicity by rice and farm runoff are polluted with nutrients and pesticides. These compounds are not good for wetlands and create eutrophication and anoxia in the lagoon areas. The seasonal flows or hydroperiods may also be incorrect, at least for some systems.

3.2 Recommendations

Develop the Plan to provide clean winter flows to these wetlands (similar to proposal for the Ebro Delta Wetlands).

3.2.1 Wetlands

The solution is the same as that proposed for the Ebro Delta Natural Areas, namely diversion of the polluted rice runoff and replacement by clean winter flows. Treatment of the pollution by constructed treatment wetlands is also possible if land is available. However, some of the chain of wetlands and lagoons has been in equilibrium with agriculture for over 1,000 years. In this case a more measured response may be required.

Removal of temporary anoxia in the wetland chain can be achieved by long-term diversion or treatment of irrigation runoff. Until this is achieved some form of artificial oxygenation/aeration/mixing is required. A pilot test project should be set up in the worst areas.

3.2.2 Expansion of bird populations

Increases in bird abundance and diversity are the best visible evidence of the improvements the Plan could make along its route. The coastal chain of wetlands and coastal lagoons are vital to the migration of many bird species. Without the food and refuge provided by this chain some birds would not be able to make the needed migration. The water needs are relatively small. The situation is virtually identical to that of the natural wetlands and lagoons that ring the Ebro Delta, namely the removal of nutrients that promote eutrophication, a guarantee of the natural hydroperiod and prevention of pesticide inflow from agricultural areas. Similar solutions should be proposed as part of the development of the Plan.

4.0 Anoxia in the Ebro Delta Salt Wedge

4.1 Findings

Anoxia (no or very low levels of dissolved oxygen) in the Ebro River Delta salt wedge threatens endangered species as well as those specially adapted to live in this highly productive habitat.

4.2 Recommendations

Develop the Plan to present details of the two solutions. In the short term provide additional oxygen by aeration or mainly solar and wind powered pure oxygen additions. In the long-term, reduce nutrient pollution and eutrophication by constructing nitrate removal wetlands along the river and where agricultural pollution enters the river. Unless supported by further studies, exclude flushing the anoxia into the sea with high water flows since this will result in the loss of the salt wedge biota, most productive community in the entire Ebro River. Anoxia is due more to nitrate pollution than to water flow regime.

4.2.1 Immediate elimination of anoxia (low oxygen) in the Delta, lower Ebro River and the large hydropower reservoirs using artificial oxygenation/aeration

The Ebro Delta Salt Wedge anoxia. Low oxygen in the Delta near the salt wedge represents a serious, if common, estuarine problem. As with most anoxic situations, the low oxygen is due to the decomposition of algae in a situation where they are transported downstream much slower than the water milieu in which they are suspended. The physical recycling action in the salt wedge is caused by the equalization of the downstream freshwater flow and the upstream counter-current of the deeper seawater. Thus the amount of water to be oxygenated does not depend on the net flow of water but a smaller quantity based on the oxygen demand of the sinking algae as they respire and decay. For example, the Thames River in England suffered very low dissolved oxygen for many years. The Thames has now been restored in large part. However, the anoxia was not a function of river flow, which has remained similar over the restoration period. The solution was a decrease in external oxygen demand, in this case industrial and domestic waste. Thus the elimination of anoxia in the Ebro Delta Salt Wedge can be accomplished without changes in water discharge.

The amount of oxygen to be added cannot be calculated precisely without access to season surveys of the extent and the anoxia and estimates of the oxygen demand. However, the mean summer rate of oxygen depletion tends to be similar in many eutrophic situations and the anoxic region is probably only a few km long. The daily oxygen demand is thus likely to be in the range of 10 to 1000 tonnes and may be needed for only 2-3 months. The approximate capital costs for artificial oxygenation are thus in the 2-5 million euro range and annual operating costs in the range of 50-100,000 euros. These costs are easily justified in terms of the restoration of the Ebro delta for endangered fish and will allow the re-introduction of now extinct migratory fish such as the sturgeon.

Sustainability of the oxygenation. Two factors should be emphasized regarding artificial oxygenation. First, without a guaranteed adequate level of dissolved oxygen in the salt wedge region the sustainable restoration of the Ebro cannot be achieved.

Second, artificial oxygenation may need to be part of the sustainable solution for many years until the upstream nutrient supply is much reduced. It may be that upstream nutrients are very difficult to reduce. One option to make artificial oxygenation fit the full needs of sustainability is to use renewable energy resources to supply the power needed to generate oxygen. Oxygenation is particularly suited to use of wind and solar energy sources since continuous production or production at any one time is not needed if the system is correctly designed. In contrast solar or wind powered domestic sources must produce every day and at fixed times, for example in the afternoon for air conditioning.

5.0 Pollution of the Ebro River Delta Wetlands

5.1 Finding: Pollution of the Ebro River Delta Wetlands

The current summer water supply to the Ebro Delta wetlands is polluted with nutrients, especially nitrate, and agricultural pesticides. The situation with the running waters of the lower Ebro River and the Delta is less clear with respect to eutrophication. Anoxia (low or no dissolved oxygen) has been reported as a major problem near the salt wedge. Such anoxia must be the result of nutrient pollution and consequent eutrophication. However, it is likely that both nitrogen and phosphorus must be reduced considerably before the Delta and lower Ebro River eutrophication is reduced to the level where anoxia will no longer be a threat to the bottom organisms. Anoxia in the Ebro River and Delta caused by excess nutrients is a prime example of a serious but easily soluble problem.

5.2 Recommendation: Pollution in the Ebro River Delta Wetlands

Revise the Plan to detail diversion of agricultural return flows to the ocean, preferably following pollution removal using wetlands and other means as needed.

5.2.1 Anoxia in the lagoons in the natural coastal wetland areas.

The coastal lagoons ring the outer Delta and are a vital component of the remaining natural areas. The lagoons are particularly important for bird life and therein lies one of the worst threats of anoxia. The oxygen depletion in the coastal lagoons is due to eutrophication caused by high nutrients in rice drainage that supplies the wetlands. Anoxia kills much of the food supply of the birds in the lagoons since most invertebrates and small fish require oxygen at all times. In addition, eutrophication is often associated with avian botulism, a bacterial disease that commonly affects wildfowl when algae and consequent anoxia are overabundant. Two solutions are currently available:

- Remove the nutrients in rice drainage using constructed wetlands
- Artificially oxygenate the lagoons.

Depending on the urgency of the anoxia problems in the Ebro Delta lagoons, the choice of solutions can be made. Unlike the eutrophication problem in the salt wedge of the main river, the nutrients that are most troublesome appear to come from only one local source – the local rice field drainage.

5.2.2 Removal of pollutants in the Ebro River Delta Wetlands

The long-term solution to anoxia and toxic pesticide and other organic pollution is the cleanup of the rice irrigation runoff combined with a cleanup of the Ebro River. Various methods are available but constructed wetlands, combined in function with the raising of the Delta elevation is the most suitable. For cleanup of the river, more methods are available and are given in the next section.

Removing anoxia from the lagoons in the natural areas of the Ebro Delta. The eutrophication responsible is caused by agricultural runoff. The problem can be solved in concert with restoration of the correct hydroperiod and was covered in an earlier recommendation. Essentially, the summer excess nutrients in the rice farm runoff should be diverted to the ocean (and possibly treated first using constructed wetlands).

6.0 Nutrients and pollution in the Ebro River and hydropower reservoirs

6.1 Finding:

Nutrients, especially nitrate and some phosphorus as well as other pollutants including heavy metals and pesticides are present in the Ebro River above the Delta. These pollutants cause eutrophication in the storage reservoirs on the river and may reduce the numbers of benthic animals and fish.

As with many waters downstream of agriculture and cities, the lower Ebro River contains large amounts of nutrients. The major problem with excess nutrients (soluble phosphate, ammonia and nitrate) is the stimulation of algae growth in the process of eutrophication. Good progress was recently made in the reduction of total phosphorus (TP) from upstream sewage treatment plants and the concentration has fallen from about 900 to 200 ug/L. However, this concentration is still well above that needed to control eutrophication in still waters (~ 20 ug/L TP) as was evident from the large surface algae blooms in the upstream reservoirs in June 2002. No action has been taken with regard to nitrogen from sewage, despite the fact that nitrogen is the usual limiting nutrient in estuarine and coastal zones.

In addition, to nutrients there are pesticides and industrial pollutants in the Ebro River and its reservoir sediments. The possible toxicity from these pollutants threatens the ecological sustainability in both the wetlands and the lower Ebro River (birds, fish and invertebrates). Recent reports on the endangered *Margaritifera* clam suggest that its recovery may be partially due to a recent reduction in industrial pollution upstream. However, no details are available and it is not clear if industrial pollution has been tackled in the same period as the phosphorus reductions cited earlier.

6.1 Recommendation

Develop the Plan to provide details of the clean-up of pollution by optimising standard sewage and industrial waste treatment for all sources (point and non-point) and treatment wetlands situated at strategic points. The Plan can only accomplish part of this solution but can provide a lead and a rationale. Reduce eutrophication by installation of wetlands on the agricultural return waters along the river where land is available.

6.1.1 Anoxia in the hydropower reservoirs and summer discharges.

It is likely, but not known to us, that the two large eutrophic hydropower reservoirs on the lower Ebro have anoxia in the summer hypolimnion (cool, deep water layer). A study of the temperature-oxygen depth profiles is needed. Artificial oxygenation of reservoir hypolimnia is a simple process and relatively inexpensive. The method can be made sustainable by the use of wind and/or solar power that is particularly suited for lake and reservoir oxygenation (see discussion for anoxia removal in the Ebro Salt Wedge).

6.1.2 Anoxia and hydrogen sulfide in the lower Ebro.

The degree and extent of any anoxia or toxic hydrogen sulfide is not known. Benthic insects in the river from the 60 km site (Xerta) to Tortosa showed some species (mayflies) normally intolerant to low dissolved oxygen. Cobbles, sand and gravel was present. Anoxic conditions were present at the near salt wedge site at Amposta. On the other hand, bottom water discharges from eutrophic reservoirs in summer usually contain no oxygen and toxic levels of hydrogen sulfide. Thus poor water quality may or may not be a problem in the lower river. A focused survey is needed.

6.1.3 Removal of nutrients and pollutants from the Ebro River.

The removal of nutrients and pollutants from the Ebro River is an essential part of what a further developed Plan should accomplish. Without a clean river, the flagship ecological sections of the developed Plan we are suggesting will always be in danger of not being sustainable. The restoration of the endangered *Margaritifera* clam and its blenny fish partner, the re-introduction of the now-extinct large sturgeon fish depend on unpolluted water.

Additional removal of nutrients using constructed wetlands. A very good start has already been made on phosphorous removal using conventional sewage treatment facilities. The removal of nitrogen, the other main nutrient important in eutrophication, is needed to ensure a sustainable future for the Ebro River wildlife. However, the cost of nitrogen removal from sewage using conventional technologies can be high. In addition, conventional techniques for wastewater treatment are very energy and materials intensive and require the disposal of large amounts of sludge. In other words, conventional sewage treatment is not sustainable. However, much more sustainable technologies are now available for wastewater and are applicable in many normal circumstances. Most prominent of these sustainable cleanup technologies are constructed wetlands specifically designed for the removal of pollutants.

The removal of nitrate and other pollutants should emphasize both source control and natural treatment systems (constructed wetlands). Source control would include reducing the amount of fertilizer used in farming to only that needed to maximize crop yield. Due to the low cost of fertilizers, most productive farms in developed countries have added so much excess fertilizer that the soils have become saturated with N and P. Another area of great concern is the handling of animal manure. As the economics of farming dictate greater yields per unit area, animal density has increased and manure production has outstripped disposal methods in most agricultural regions.

In general, the wetlands systems similar to those recommended for the treatment of rice runoff would also be suitable for polishing municipal wastewater and other kinds of

agricultural discharges and storm runoff. However, different kinds of treatment wetlands can now be designed for different kinds of pollution. In addition, the location of the wetlands for treatment for the middle river from Zaragoza to the Delta can be located in more convenient and less costly land than in the Delta below the rice farms runoff. Finally, there are additional benefits available from Natural Treatment Systems, the new designs of wetland that remove pollution and provide excellent wildlife habitat. The wildlife benefits from wetlands in the California constructed over the last decade have proven very popular with the public. Similar popular projects would benefit the developed Plan.

Organic and heavy metal pollutants removal. As with nutrients that create eutrophication and anoxia, pesticides and heavy metal pollution is not compatible with a sustainable Ebro River. Equally important, the export of toxic material to other drainages is not a practice that should be encouraged. However, the same mixture of source control, conventional waste treatment and polishing with constructed wetlands will result in a river clean of both nutrients and toxic pollutants such as copper, zinc, mercury or pesticides.

It is recommended that the Plan be developed further to include a general assessment of the role the Plan could play in supplying upstream treatment wetlands with water in dry periods. Similar plans for the use of wetlands in urban and rural areas are in progress in Las Vegas, Nevada and Southern California.

Integrated river pollution protection (IRPP). A much better total integrated mean of protection for the river is to combine a relatively narrow riparian strip with constructed wetlands. The riparian strip provides snags, leaves and falling insects as well as some near-bank shade. Nutrient and pollution protection can be proved by wetlands constructed adjacent to the river where land is available. Water is diverted from the river, cleaned up and returned. If properly designed such wetlands are far more efficient than natural wetlands or very wide riparian corridors and much less total land is needed. Examples in Southern California have been spectacularly successful for example reducing nitrate from 10-15 mg/L-N to ~ 1 mg/L-N (Reilly et al., 2000). Similar systems have been proposed to eliminate the nitrate pollution problems in several rivers including the Thames (UK), Ouse (UK), Mississippi (US), and Rhine (Germany) and require about half of the original flood plain (Horne, 2002).

Other pollutants such as heavy metals, pesticides, organic sediments and pathogens are removed by constructed wetlands if the hydrology is appropriate. In this case the wetlands must be permanently flooded, not seasonally desiccated (Horne, 2000). Permanent wetlands are vital for the immobilization of pollutants such as heavy metals and pesticides. The needed year round water supply to the IRPP wetlands in the Ebro River should become part of the developed Plan.

A great advantage of the IRPP is that, again if properly designed, permanent constructed treatment wetlands are wonderful wildlife habitats. As an example the 50 ha nutrient removal wetland in Irvine California (IRWD.com) removed nitrate down from 13 mg/L-N to 1-3 mg/L in about one-third of the flow of San Diego Creek while attracting over 200 species of birds. One of the earliest wetlands in California in Humboldt County, polishes municipal wastewater but has become one of the most important bird habitats in the region attracting thousands of visitors to this remote northern town.

7.0 Lack of habitat in the Ebro River

7.1 Finding

The Ebro River has a low benthic biological diversity due to loss of habitat as well as pollution and eutrophication. Gravel beds for fish spawning are not being replenished due to upstream dams and the riparian (tree fringe) corridor and submerged snags are minimal.

7.1.1 Water quality in the Ebro River(freshwater section above the salt wedge)

Biota. Some of the most sensitive aquatic species in the world are present in the lower, freshwater section of the Ebro River. In particular, the large freshwater clam *Margaritifera auricularia* and its associated fish species are found only in this section in the entire world. *M. auricularia* was once present in many European rivers and could be re-introduced to these lost sites. At present it is endangered and uncommon in the Ebro and is in danger of extinction. Sustaining *Margaritifera* is thus of very special interest to the Plan

Historically, this species and other similar large freshwater clams, are typically the first ones to disappear following development in the region. Thus it is unlikely that pesticides and complex anthropogenic chemicals are the reason for loss of freshwater clams since most had gone from most European and US rivers before such chemicals were invented. Similarly, sediments are unlikely to be the reason for clam losses since a related *Margaritifera* species is still found in abundance in rivers in England with high sediment loads. Also, the Ebro had enormous amounts of sediment passing through the system in the 15-16th centuries when the current delta was being laid down.

The most likely cause of freshwater clam demise in rivers is lack of oxygen. Anoxia in rivers is common and due to the discharge of untreated or partially treated sewage and eutrophication. Most large sewage plants in the region were recently upgraded and, in any event, are mostly so far upstream that most oxygen demand would be satisfied by re-aeration in the river before the lower Ebro was reached. In contrast, recent developments over the last 50 years in agriculture have greatly increased the nutrient load to the lower river. As was discussed for the delta salt wedge anoxia, nutrients produce eutrophication and algae that produce anoxia in the river water during summer.

Hydrogen sulfide. In addition, to direct anoxia produced by decomposition of algae in the river, poor water quality may be due to releases from the two large hydropower dams (Mequinenza & Ribarroja). In our over-flight of these reservoirs the surface scum of blue-green algae was evident and the amounts of nutrients in the river would support the maximum algal crop in still water. The Plan provides no details of the water quality in the reservoirs in particular the amounts of algae and the depth profiles for temperature, dissolved oxygen, and hydrogen sulfide. Hydrogen sulfide accumulates as a dissolved gas in the deep stratified hypolimnion of eutrophic lakes and reservoirs. Hydrogen sulfide is of particular interest since it is very toxic to fish and aquatic life but is not easily reduced by conventional reservoir discharge techniques such as aeration of the outflow. In addition, aeration to remove hydrogen sulfide is incompatible with hydropower generation.

Hydrogen sulfide is the probable cause of many fish kills through the world. In a recent Californian example, artificial oxygenation was used to reduce hydrogen sulfide within Comanche Reservoir ($V \sim 400 \text{ hm}^3$) The hydrogen sulfide killed fish both in the reservoir hypolimnion (cool deep water) as well as in the river and fish hatchery downstream. Hydrogen sulfide is a particular problem because it takes several hours in the presence of oxygen before the sulfide is converted to harmless sulfate. Thus vigorous aeration at the outlet of the reservoir restores dissolved oxygen in seconds but does not guarantee removal of hydrogen sulfide toxicity. Since oxygenation was begun in Comanche Reservoir, no fish deaths have occurred over ten years and eutrophication was reversed with chlorophyll levels falling to almost 10% of pre-oxygenation levels.

Hydrogen sulfide may be a serious, if occasional toxic event in the lower Ebro below the large dams. Since *Margaritifera* clams are long-lived, a hydrogen sulfide release every few years would be sufficient to threaten large section of the population 5-10 km downstream. The removal of hydrogen sulfide from the hypolimnion and power releases of the two large hydropower reservoirs will be discussed in the recommendations section. The method recommended is artificial oxygenation that also imparts other water quality improvements.

Benthic habitat. In addition to a requirement for good water quality, the lower Ebro River requires sediments appropriate for the habitat of the individual species. However well flushed gravel and sand beds are important for many organisms as spawning areas and habitat. The importance of the coarse sediments is twofold. First, the lack of fine sediments allows free flow of water and life-giving dissolved oxygen to penetrate between the gravel and support fish eggs and small fish larvae. Second the same process provides habitat for insect larvae that are the main food supply for larger fish. The insect larvae hide from predation under well-oxygenated cobble or small rocks. In most rivers the decline of the fishery and its insect food supply is either due to low oxygen in the river or the filling in of the gravel with fine sediments. Sometimes armoring of the gravel caused by excess organic pollution or nutrient-driven algal growth produces the same effect of restricting oxygen penetration.

Clean well-oxygenated gravels are important for several Ebro species including the rare *Margaritifera* clam and spawning for several fish including the now-extinct sturgeon. The sturgeon could be re-introduced from stocks from other rivers if suitable habitat were provided. The lack of upstream sediments that supply the gravels for fish and clams has been noted in many reports on the Ebro River. Lack of new sediment degrades river habitat. Details of possible methods to improve habitat in the lower Ebro will be presented in the recommendations section.

7.2 Recommendation

Develop the Plan to include flow regimes and dam modification for inorganic sediment transport (see recommendation of Delta inorganic sediment replacement). Provide details for re-introduction of the riparian forest where needed and add new snags (large tree stumps) as needed.

7.2.1 Restoration of snags and some riparian vegetation in the lower Ebro River

In most rivers with a fairly constant summer flow, the riverbanks are wooded. This riparian corridor provides benefits for aquatic and terrestrial biota alike. Large trees provide some food for the aquatic invertebrates in the form of dead leaves and insects that fall into the water. Some shading is also provided but has less effect in wider rivers. Most importantly, large trees provide aquatic habitat when they fall into the river. The value of the habitat provided by large woody debris provided by dead trees has only recently been appreciated. The boles of the trees and larger branches provide an area that has much more favorable water flow conditions than the fast, one way flow of the main river channel. Fish can use the back eddies produced by the snags to rest and then dart out to catch passing prey. Invertebrate densities are higher in the snag regions than in other parts of the river.

Snags are not temporary features as might appear. Due to the lack of oxygen in water relative to air, lignin-decomposing fungi cannot grow. Thus large snags may persist for hundreds of years. The developed plan should determine if the reintroduction of snags is appropriate for the ecology of the Ebro River. In this technique, fallen dead trees including stump and some roots are fastened to the riverbank and part of the riverbed in suitable spots. The current lower river is depleted in these essential physical features that are beneficial to fish. Experience in California is that replacement is feasible and self-sustaining.

A potential problem may occur which is common to dry regions where native fish are often isolated and exotic fish have been introduced. The Ebro is such a river and is even contaminated with introductions of American fish species. In some cases the snags might provide better habitat for introduced nuisance predators such as the bullhead than native species.

7.2.2. Riparian Corridor

The width of river riparian corridors needed to provide an ecological benefit range from 1 to 30 m. For large rivers it is not clear what width is needed but only the trees close to the river directly provide leaves, insects, snags and shade. In Ireland and England, buffers of 1 m have been very successful in riverbank stabilization and allowing riparian growth to re-establish. This kind of narrow riparian corridor has the advantage that little farmland or other land is needed compared with, for example, 30 m wide riparian zones. Wider riparian zones have been shown to be useful in surface flow pollution but such flows are very rare, except in case of logging or where urban impermeable surfaces are involved. Such surface flow pollution may be expected to be rare in the Ebro River.

8.0 Possible inappropriate hydroperiods for the Ebro River Delta wetlands

8.1 Finding

On some occasions, the hydroperiod (seasonal flows) to the fringe of wildlife habitats on the coastal edge of the Ebro Delta may be reversed from the natural pattern. Pools in the current wetlands are eutrophic and become depleted in oxygen so do not sustain a full biotic component and risk fish and bird kills.

Some of the most important areas directly affected by the Plan's water diversions are wetlands characterized by some period of shallow water, hydric (anoxic) soils, and the presence of plants specially adapted to flooded, anoxic soils. The single most important factor in wetlands ecology is the hydroperiod (timing of seasonal flows). Seasonal wetlands in Mediterranean climates have a winter-spring hydroperiod and are either dry or saline in summer. Permanent wetlands close to the coast have a winter-spring freshwater supply that is partially replaced by brackish seawater in summer. The current water supply to the Ebro River Delta does supply water in winter but there may also be a summer flow as tail water from rice farming.

A summer freshwater supply can provide wetlands that are used by wildlife, so are not a complete loss. However, the supply of rice tailwater rich in nutrients and pesticides is not a sustainable solution. The nutrients cause eutrophication and consequent areas of anoxia in the Delta lagoons of the natural areas bordering the sea. The Mediterranean Sea is very poor in nutrients so the supply of high nutrient water in the summer growth season is particularly undesirable. It would be possible to design a treatment wetlands system to remove the summer nutrients but this would require a considerable amount of land to be taken from rice production. Such a wetland treatment system could be incorporated into the land elevation project or replaced with a dual water system (see recommendations).

8.2 Recommendation

To ensure the sustainable mandate of the Plan develop methods to guarantee drainage patterns approximate the natural hydroperiod. Agricultural runoff should be cleaned using constructed treatment wetlands and/or diverted as detailed elsewhere.

APPENDIX C: ECONOMICS

BY: MICHAEL HANEMANN

ECONOMIC FINDINGS AND RECOMMENDATIONS

In the documents we received, there was no economic analysis relating to the need for upstream storage or irrigation within the Ebro River basin. The materials we received contained economic analyses relating to the uses of water in Barcelona and in the Jucar and Segura basins. Therefore, we are not in a position to offer any comments on the benefits or costs of any water development that might be contemplated within the Ebro River basin.

Our discussion of the economic analyses concerning the delivery of project water to the Barcelona and the Jucar and Segura basins focuses on (1) the options considered in the Strategic Environmental Assessment (SEA), and (2) the economic analysis of these options as described in the volume of the NHP containing the Economic Analysis (EA). Our discussion here is based on the information in these two documents as supplemented by information that was presented to us during our meetings in Spain in June and in Berkeley in November, and information in documents that we have received following our visit to Spain.

1. The Selection of Options for Consideration in the Strategic Environmental Assessment

The SEA identifies four alternatives. One alternative is "No Action." Another is the inter-basin water transfer of 1050 hm³ annually from some other region. A third is to provide 1050 hm³ annually through desalination. The fourth is to have no transfer from another region, improve irrigation and water use efficiency in the receiving areas where possible, and otherwise shut down farming operations on lands now supplied by overdrafting groundwater aquifers.

It is not clear to us how the last alternative differs in practice from the No Action alternative; both would entail very similar consequences. Therefore, for all practical purposes it seems that the SEA considers three real alternatives:

- Supply 1050 hm³ to the receiving areas via a transfer from another region.
- Supply 1050 hm³ to the receiving areas via desalination.
- Provide no new source of water to the receiving areas, and allow the consequences to unfold.

This set of alternatives does not allow for any variation in the size of the planned augmentation of water supply in the receiving area.

In the United States, it is not now the practice to treat the amount of the diversion as all-or-nothing proposition when conducting an environmental impact assessment for a major water policy action. In order to comply with the National Environmental Policy Act, US government agencies would now have to consider some alternatives involving different amounts of diversion.

The 1050 hm³ of water to be diverted annually by the project consists of three components: water needed to meet the future growth of urban and industrial use (440 hm³), water intended to be used to eliminate the existing overdraft of groundwater by agricultural users (340 hm³), and water needed to guarantee supply reliability for existing agricultural users (220 hm³). The EA provides some explanation for the derivation of the specific quantity allocated to urban and industrial use, based on population projections and estimates of future per capita urban and industrial use. But it does not provide any economic justification for the specific quantities allocated to the two elements of agricultural use.

2. The Economic Analysis of the Options Considered

The EA report presents an analysis of the costs and benefits of the proposed transfer of 1050 hm³ annually from the Ebro basin to Jucar and Segura basins. We comment first on its analysis of the costs, and then the benefits.

3. Costs

The EA states that the average annual cost of water delivered to the receiving regions will amount to 52 pts/m³ in current prices.²

The experience with water projects in the United States, including the Central Valley Project of California and the Central Arizona Project, has been that they typically end up costing significantly more to construct than was originally anticipated. One reason is that construction takes longer than originally planned, thereby delaying the start of water deliveries; with discounting, this raises the cost of project water. Another reason is that the project may initially deliver less than the full volume of water, and subsequent deliveries may ramp up more slowly than originally anticipated, thereby raising the cost per unit volume. A third reason is unanticipated cost increases during the process of construction. We understand that there is some allowance for the first and third items in the SHNP cost analysis; we have not reviewed the analysis in detail and cannot assess the treatment of those items. In order to deal with the second item, we will recommend below that the Spanish government conduct a detailed marketing assessment for the Ebro River transfer in order to obtain a realistic estimate of the timing and extent of the market demand for this water in the various receiving areas.³

We understand that, in its treatment of electricity costs, the EA report uses slightly different prices to value the cost of power used in pumping project water versus the benefit of surplus hydropower generated by the project and sold to outside users, based on government set rates for different types of user. However, for the purposes of an economic analysis, the electricity used by the project should be valued at its opportunity cost. Consequently, the same price should be used to value both the electricity used by the project and the electricity generated by the project.

The SEA implies that the project water will not be of significantly worse quality than the existing water used in the receiving areas. However, if the quality of imported project

² In US units, this is equivalent to about 385 Euros per acre foot.

³ The timing also has implications for the calculation of benefits. In some places, the EA report appears to assume that the project generates benefits within one year when this is not plausible

water did turn out to be lower, this would impose some economic cost for users that would need to be accounted for.

Two other aspects of the cost analysis in the EA report merit some comment.

One pertains to the *compensation cost* component of project costs. The cost of compensation is a charge per m³ of water exported that is intended to reflect, at least in part, the adverse environmental impacts within the Ebro River basin as a result of the export of water from the basin. In the EA report, this charge was set at 5 pts/ m³; the revenue from this charge is earmarked for funding environmental improvements within the Ebro River basin. However, this is an administratively determined charge, not one based on economic analysis. While the SEA identifies some adverse environmental consequences that will occur in the Ebro River basin, it did not conduct a non-market valuation exercise to quantify these damages in monetary terms, and the proposed compensation charge of 5 pts/ m³ should not be taken as an estimate of the economic value of these impacts. To the extent that these impacts are not mitigated, we recommend that the Spanish government undertake a non-market valuation study to quantify them and incorporate them in the economic analysis.

Secondly, we should note our concern that, by emphasizing the average cost of water for the overall project, the NHP may intend to set a uniform price for project water throughout the receiving areas. The practice of charging a uniform price for water delivery regardless of the distance and the cost of pumping water from the original source -- known sometimes as "postage stamp" pricing -- was historically common in Bureau of Reclamation projects, and is used in the Bureau's Central Valley Project in California, which is heavily subsidized by taxpayers, but *not* in the California State Water Project, which is not subsidized by taxpayers. However, postage stamp pricing of water violates all principles of economic efficiency. The marginal cost of delivering Ebro River water to users in the service area is likely to vary quite substantially from the northern end to the southern end because of the great distance over which the water must be transported. Given the spatial variation in delivery cost, it would be economically indefensible to employ spatially uniform, postage stamp pricing in this project.

4. Urban and Industrial Benefits

As noted earlier, the project will deliver 440 hm³ of water annually to urban and industrial users in the receiving areas, and 560 hm³ to agricultural users. The EA report uses two separate procedures to measure the direct economic benefits to the two groups of beneficiaries. We focus here on the economic analysis of benefits to urban and industrial users.

In the EA, the benefits to urban and industrial users are assessed by comparing (wholesale) cost of the transferred water for these users with the cost of obtaining the same quantity of water at the same location through the desalination of seawater, which is taken to be the alternative source of supply. The difference in cost between desalinated water and imported water is taken as the measure of the benefit associated with this component of the project deliveries. In effect, the EA takes the position that the extra increment of water is going to be needed anyway, and the only issue is how it will be supplied -- from desalination or imported water. Underlying this approach are two implicit assumptions: that urban and industrial demands are totally inelastic, and that

desalination is in every case the lowest cost alternative to obtaining water from the Ebro River basin. If these assumptions are incorrect, the approach adopted in the EA will tend to overstate the benefits of imported water for urban and industrial users.

If demand is not totally inelastic, whether or not urban and industrial users are going to want an additional supply of 440 hm³ water depends on the price they will be charged for this water – the higher the price, the smaller the additional quantity they will want. Moreover, one would expect their marginal willingness to pay to decline with quantity. Therefore, the marginal benefit per m³ of water imported for urban and industrial use would not be constant but, instead, declines with the quantity imported. The speed with which it declines is related to the price elasticity of demand – the more highly elastic the demand, the faster the marginal willingness to pay declines.

In the case of urban demand, the empirical evidence in the United States suggests that most components of urban demand are almost totally inelastic in the short run, but in the long run there is a small elasticity on the order of about –0.35 overall. Given the 50-year planning horizon, the long-run elasticity should apply to at least part of the economic analysis of the NHP.

In the case of industrial water use, the experience in the United States suggests that the demand elasticity could be higher. Although the US economy has grown considerably over the past 30 years, industrial water use in the US has actually *fallen* in absolute terms (total water use has decreased, not just water used per dollar of output). This is believed to be the result of pollution control regulations starting in 1972 that significantly raised the cost of using and disposing of water in manufacturing industry. We were not able to perform a detailed analysis of the industrial demand projections used in the NHP, but our impression is that they may not adequately allow for the future effects of pollution control regulations and technical change on industrial water use in Spain.

For these reasons, we recommend that the Spanish government conduct an economic analysis of the long-run elasticity of demand for urban and industrial uses in the project service area, and integrate the results into its economic analysis of the project's benefits to these users.⁴

A similar conclusion applies to the implicit assumption that desalination is the lowest cost alternative to obtaining water from the Ebro River basin.

In the United States, increasing attention is being given to demand management involving various forms of water conservation as potential mechanism for meeting additional urban needs for water. In California, this has been recognized through the 1991 Memorandum of Understanding on Urban Water Conservation, which identified various Best Management Practices (BMP) for urban water conservation that all the major urban water agencies in California have now committed themselves to adopting. It also created the Urban Water Conservation Council to oversee the future development of additional BMPs for urban water conservation and to carry out calculations of the savings to be expected from these BMPs and the costs of implementing them.

⁴ While Figure 38 of the EA report does present some demand functions, there is no description of the source of the data, the method of estimation, or the nature of these demand curves, including whether they are short- or long-run demands and what other variables are being controlled for.

Using such information on the quantities of water likely to be saved by various conservation practices and the associated costs of implementation, and arranging the alternatives from least cost to highest cost, it is customary to develop what is known in the US as a *conservation supply curve* which shows the amounts of water that can be obtained through different conservation measures at successively increasing cost. The conservation supply curve would be integrated with a conventional supply curve of water from alternative additional sources (such as water market purchases, treated wastewater effluent, and desalinated sea water) to produce an integrated overall supply curve of water. The cost savings from the use of imported water from the Ebro River project would be calculated by reference to this integrated overall supply curve. If it turned out that there was no other source in the integrated overall supply curve that was cheaper than desalinated seawater, then the calculation of cost saving performed in the EA would be correct. However, to the extent that analysis of the appropriate conservation supply curve and the resulting integrated overall supply curve revealed the existence of some sources that were cheaper than desalinated sea water, the EA analysis would need to be modified to account for this fact.

We recommend, therefore, that the Spanish government conduct a detailed analysis to develop conservation supply curves for urban and industrial uses of water in the project service area, and integrate the results into its economic analysis of the project's benefits.

With respect to the comparison of the costs of imported and desalinated water, we believe it is necessary to investigate the possibility of further improvements in desalination technology between now and the time when the project water becomes available. There have recently been striking advances in desalination technology, and the cost of desalinated water has fallen by about half compared to what it was 10 or 15 years ago. It seems unlikely that there will be *no* new technological change leading to further reductions in the real cost of desalinated water by the time the project is completed. We recommend that the Spanish government conduct a study dealing with the issue of technical progress in desalination technology between now and when the project is completed, with the results to be incorporated in the economic analysis of the project's benefits.⁵

5. Agricultural Benefits Associated with Elimination of Groundwater Overdraft

As noted earlier, the project will deliver 340 hm³ of water annually to agricultural areas currently experiencing groundwater overdraft, which is intended to eliminate the overdraft in these areas. The analysis in the EA states that, during the course of the 50-year planning horizon, farmers in the receiving areas will have to reduce their annual pumping of groundwater by 340 hm³, which is equivalent to about 9% of the water currently being used for irrigation in these areas. The imported water will replace this lost supply.

The EA measures the benefits from this imported water based on the estimated *average* value product of the water. This starts with a calculation of the amount of irrigated

⁵ If there are further reductions in the cost of desalinated water, it could become more attractive than imported project water for some agricultural users in the south; this, too, needs to be accounted for in the economic analysis.

farmland in the receiving areas that, in the absence of water imports, will go out of production due to exhaustion of the available groundwater supply. The report estimates that about 41,000 ha of irrigated farmland in these areas will go out of production due to exhaustion of groundwater within about 12 years, and a further 21,000 ha will go out of production within between 12 and 50 years. The import of project water is assumed to prevent the idling of this 62,000 ha of farmland, which amounts to just fewer than 10% of the irrigated acreage in the receiving areas. The report estimates that the average annual irrigation application on this land is about 5500 m³/ha (hence the estimate of 340 hm³).⁶ The report next estimates that the net revenue per hectare on this land (gross revenue minus variable costs of production) amounts to about 700,000 pts/ha;⁷ given the irrigation application, this amounts to roughly 125 pts/m³ of applied water. This is used as the value per unit of project water earmarked for the elimination of groundwater overdraft.⁸

The report checks the results of this analysis by reference to what is known as an *ability to pay analysis*. This is related to the previous analysis, and it uses much of the same data. The ability to pay analysis examines the revenues and costs associated with agricultural production and the resulting profit per hectare, and then identifies a maximum price that farmers ought to be able to pay for water and still make a profit. In performing this analysis, the EA refers to some agricultural demand curves for water and makes an allowance for the fact that, at a higher price, farmers would slightly reduce the quantity of water they apply, reflecting the price elasticity of demand. Except for this adjustment, the ability pay analysis is essentially identical to calculating the average value product of water.

The economically correct way to measure the benefit from an increment in water supply for farming in the receiving areas is to measure the *marginal* value of water (marginal net profit) in the uses to which it will be put. From this, one can estimate the loss of profit (or producer's surplus) associated with the reduction in water supply that is avoided through the importation of project water. What the EA uses to value project water – namely, 125 pts/m³ -- is its estimate of the ratio of profit to water use. In using this ratio to approximate the marginal value of project water, the EA report makes two key assumptions. It interprets this profit as exclusively a return to water, and it treats this rate of return as constant independent of the amount of water supplied. We do not agree with these assumptions. Rather than a return to water, the profit is likely to be a return to the farmer's investment in land and other fixed assets, and also a return to the farmer's own labor and his family's labor. And, rather than the average value of water being constant in the receiving areas, there are strong theoretical and empirical reasons to believe that the average value declines as more water is supplied, with the marginal value of water therefore lying below the average value.⁹ If one were considering the total elimination of farming across a large portion of the irrigated acreage in the receiving areas, the difference between the average and marginal value could be of little significance, but the change here involves about 10% of the irrigated farmland and 9% of the water supply in the receiving area. With varying land quality and the opportunity to grow different crops, farmers in the region are likely to respond to any reduction in water supply by idling their

⁶ In US units, this amounts to about 1.8 acre foot per acre.

⁷ This is equivalent to about 1700 Euros per acre.

⁸ This is equivalent to about 925 Euros per acre foot.

⁹ For example, the agricultural production functions exhibited in section 4.3.4.1 of the EA clearly show diminishing returns to the input of water for each individual crop, which implies that the marginal value of water lies below the average value.

least productive land and discontinuing their *least profitable* crops. Consequently, we believe that the reduction in total profit would be disproportionately smaller than the reduction in total water input, and the marginal loss of profit would be less than the average profit per acre.

One piece of evidence which suggests that the marginal value of water in the receiving areas is less than 125 pts/m³ is the fact that most farmers in these areas pay prices for water which are substantially lower than 125 pts/m³. Table 35 of the EA report presents a series of different estimates for the cost of irrigation water in the receiving areas, including the cost of groundwater pumping. These costs, taken from various authors, vary considerably, but they are all substantially lower than 125 pts/m³. Under the conventional economic assumption of unconstrained profit maximization, one would expect that the marginal value of water is equal to its marginal cost. We realize that, in practice, there may be some limits to the amount of water actually available to farmers, which would produce a gap between the marginal value (the shadow price) of water and its actual price. But the fact that what farmers pay now is so much lower than 125 pts/m³ is *prima facie* evidence that the marginal value of water is likely to be some amount lower than 125 pts/m³.

It should be noted that the economic analysis in the EA report focuses narrowly on the use of groundwater within the receiving areas and does not address the interactions with surface water supplies within the region. However, we understand that some, perhaps many, users of groundwater also have access to some surface water supply.¹⁰ Our impression is that, in varying ways and to varying degrees, the supplies of water for farmers in the receiving area are interconnected, and water is a relatively fungible commodity. This has two important economic implications.

First, since the imported project water is one among several sources of water for irrigation, what is required in order to evaluate the project is an estimate of the farmers' demand function for project water, *not* their demand function for water overall. While the EA report does present some agricultural demand functions for water, these appear to be demand functions for water overall, not specifically demand functions for project water.¹¹ Because of the availability of substitutes, the agricultural demand function for project water is likely to be more elastic than the demand function for water overall. We therefore believe that it should be a high priority for the Spanish government to conduct a study to identify the existing mix of supply sources for different groups of farmers who are targeted to receive imported project water and, in the light of this, to assess their demand functions specifically for the project water.

The second point concerns the prices for water that will farmers in the service areas will be paying at the time when water from the project becomes available. It is important to know these prices with some specificity for two reasons. One reason, alluded to above, is that this can shed some light on the marginal value of water for these farmers, which is important for the benefit cost assessment. The other reason is that it is important to have a clear idea of the cost differential, if any, between the cost of the newly imported

¹⁰ We were told that, because of this interconnectedness, new local distribution canals would not generally be required in order to distribute imported Ebro River water to former groundwater users.

¹¹ See Figures 40 and 41 in the EA report. We are not sure what is the data from which these demand curves are estimated. They appear to be highly aggregated over broad regions, and they do not appear to control for factors such as cropping patterns, input price, groundwater availability, crop marketing channels, soil type, etc which could lead to variation in demand at the micro level.

project water and the cost of the existing supply sources at the time when the transition to imported project water is expected to occur because this affects the farmers' demand for project water. Given a non-zero elasticity of demand, if the imported project water turns out to be more expensive than other sources of supply within the receiving area, including water obtainable through local water markets and informal exchanges, there would be less demand for project water than if there were no such price differential.

The EA report does not project future water prices in these areas, nor does it provide precise or specific information regarding the current level of water prices. It notes the methodological difficulties of identifying a representative price because of the diversity and complexity of the existing pricing arrangements. It lists half a dozen different sources of information on water prices in the region which produce quite divergent information – one study gives the price of groundwater as ranging from 0 to 15 pts/m³, for example, while another study gives a range from 20 to 35 pts/m³. We believe it should be a high priority for the Spanish government to conduct a more definitive study to identify both the existing cost of water supply and the anticipated future cost at the time of project completion for different groups of farmers who are targeted to receive the imported project water.

These two studies – a study of the demand for project water and the study of the cost of water from other sources within region – complement one another and should be viewed as two parts of an overall marketing study designed to measure the marginal willingness to pay of the farmers who are the intended users of the project water and to ensure that the planned sale of imported project water is financially feasible.

The study we are recommending is quite different from the ability to pay analysis that is contained in the EA report. This ability to pay analysis is not an acceptable substitute for the marketing study that we are recommending here. An ability to pay study measures what a farmer could pay – in effect, it measures the maximum price farmers could pay without making zero profit. But, most farmers seek to maximize profit, not just to break even. Hence, the ability to pay analysis is a poor guide for predicting what farmers will actually do. In contrast, the marketing study measures what the farmers are likely to be willing to pay. What farmers are willing to pay is less than what they could pay; therefore, the ability to pay analysis overstates willingness to pay. In effect, the ability to pay analysis measures the average profit from the use of water, while the willingness to pay analysis measures the marginal profit. It is the latter that one needs to know both for an economic benefit cost analysis and for assessing the project's financial viability.

In the United States, the Bureau of Reclamation's use of ability to pay analysis is widely discredited among outside analysts; the experience in the US has been that the ability to pay analysis is highly unreliable as a means of predicting the actual demand for project water and consistently overstates this demand.¹² The resulting shortfalls in demand have forced the Bureau to lower prices to agricultural users well below the levels predicted on the basis of ability to pay; this happened with the Central Valley Project in California and, most catastrophically, with the recent Central Arizona Project where several major irrigation districts were driven into bankruptcy by the cost of water which an ability to pay analysis had wrongly concluded they could afford.¹³

¹² See, for example, Wahl (1989) and Wilson (1997)

¹³ As explained in Hanemann (2002), CAP is the largest and most expensive water project ever constructed in the US. It was completed in 1992 at a cost approaching \$5 billion. It was designed to provide a

6. Agricultural Benefits Associated with Enhanced Reliability of Agricultural Supply

In addition to irrigation supplies intended as a substitute for groundwater in overdrafted areas, the project will also deliver 220 hm³ of water annually that is intended to augment supplies in currently irrigated areas which are deemed to have an inadequate or unreliable water supply.

The economically correct way to assess the benefit from these deliveries is to assess the marginal value of the water in the uses to which it will be put. In effect, one would be measuring the marginal value of an increase in reliability for agricultural users. For example, having a more reliable water supply could permit some farmers to plant different crops in years when water supplies are low; in that case, the economic value of a more reliable water supply would be measured by the increase in net profit associated with the change in cropping pattern that this permits in dry years, weighted by the frequency with which these dry years occur.

The EA report uses the following methodology to measure the economic benefit from enhanced reliability of agricultural supply. The report estimates that 40,364 ha suffer from inadequate or unreliable supply and will benefit from this delivery of project water. In these areas, the imported water represents an increase amounting to 7% of the existing total supply. The EA report then assumes that the marginal value of water in these areas is roughly constant and is identical to the average value of water, which it continues to assess at 700,000 pts/ha, or 125 pts/m³. Thus, report assumes that a 7% increase in irrigation supply to one hectare of this farmland raises the profit from farming on that hectare by 7% of 700,000 pts, or 49,000 pts/ha. This is applied to the total of 43,364 ha to generate the estimate of annual benefit from this supply.

This is not an accurate way to measure the economic benefit from the increased reliability of supply. Instead, the Spanish government should conduct an economic analysis along the lines outlined above which explicitly identifies both farmers' marginal loss of net income in years when they face uncertainty of supply, taking into account the alternatives available to them, and the frequency with which these years occur.

replacement supply of surface water from the Colorado River for farming areas in Arizona that were dependent on declining groundwater resources, and it was predicated on forecasts that irrigated acreage in these areas would be forced of production due to depletion of the groundwater supply. After the project was constructed, the reality turned out to be that farmers were able to continue pumping groundwater for much longer (and from greater depths) than the planners had projected. Consequently, the anticipated agricultural demand for imported project water did not materialize as the planners had expected. The result was that several large irrigation districts created for the purpose of distributing imported project water were forced into bankruptcy. The project has turned out to be economically unsustainable. However, CAP is by no means unusual in this regard; in fact, it is highly representative of the overall experience in the United States with large water projects. Between 1902 and 1994, the federal government spent \$21.8 billion to construct 133 water supply projects in the western states. The share of this cost assigned to be paid by irrigation users was \$7.1 billion. Of that amount less than \$1 billion had actually been repaid as of September 30, 1994; the remaining obligation will not be repaid until well into the 21st century, many decades behind schedule (US General Accounting Office, 1996).

7. Other Items To Be Included in the Economic Analysis

Having reviewed what is included in the EA analysis, we should comment on two noteworthy omissions.

Missing from the EA report is any allowance for economic uncertainty; the analysis is conducted as though, over the fifty-year life of the project, there were no uncertainty regarding any of the economic variables. This is unrealistic. There are many important economic uncertainties including: future changes in the EU's common agricultural policy (CAP), which could reduce or even eliminate the present system of production-based commodity subsidies;¹⁴ the Doha Round of world trade negotiations, which could lead to a substantial reduction in EU tariffs on farm products and could benefit producers in North Africa who compete with the agricultural users of the project water; changes in the availability of inexpensive farm labor from North Africa, which is an important prop for agriculture in the receiving areas; modernization of farming and the consolidation of small farms in the receiving areas; changes in energy prices; and the potential effects of climate change, both physical and economic.

These uncertainties need to be factored into the economic analysis. At the very least, there should be a sensitivity analysis to identify how alternative outcomes of these uncertainties might affect the estimated benefits and costs associated with the project.

The second noteworthy omission is any explicit economic evaluation of the project's environmental impacts, both negative and positive. As noted above, the compensation cost is intended, at least in part, to account for the adverse environmental impacts within the Ebro Basin, although not outside it, but this is not based on any economic analysis. In the United States, it would not now be acceptable to perform an economic assessment of a major water project without including some non-market valuation of the project's environmental impacts.¹⁵

It should be emphasized that the use of non-market valuation applies to positive as well as negative environmental impacts. The EA fails to consider the potential environmental benefits associated with using opportunities afforded by the project to *improve* environmental conditions both in the Ebro Basin and in the receiving areas – opportunities to raise water quality and improve ecosystem habitat, enhance the water supply for wetland areas and nature preserves, etc. The experience in the United States has been that these can generate significant economic benefits associated with water-based recreation, eco-tourism, and the non-use value of ecosystem protection that in some cases outweigh the benefits from agricultural or even urban water use.¹⁶

¹⁴ We understand that few farmers in the receiving areas grow the crops that are most heavily protected by CAP. However, other parts of Spain do benefit from the protection of CAP and it is necessary to check whether any change in CAP could lead to a re-location of agricultural production within Spanish agriculture that might impact the economy of the receiving areas.

¹⁵ For example, non-market valuations of environmental impacts were included in the California State Water Resources Control Board's review of the water rights of the Central Valley Project and the State Water Project, and in its Mono Lake Decision. Likewise, they were included in the Bureau of Reclamation's assessment of the Central Valley Project Improvement Act and the Department of Interior's re-assessment of the operation of Glen Canyon Dam on the Colorado River.

¹⁶ For example, in its Mono Lake Decision the State Water resources Control Board decided that it was in the public interest to reduce Los Angeles' diversion from Mono Lake by about two thirds, despite the resulting loss of hydropower and water supply (which amounted to over 8% of Los Angeles' total water supply) primarily in order to protect habitat for birds and other wildlife; non-use values associated with

8. Conclusions

We have identified aspects of the economic analysis in the EA report that need to be corrected. Some of these corrections, involving the studies we recommend regarding urban, industrial and agricultural benefits, are likely to lead to reduced estimates of these benefits. However, if the project were to be redesigned with the objective of improving environmental conditions both in the Ebro Basin and in the receiving areas, and a non-market valuation study were to be performed that accounted for environmental benefits as well as costs; it is quite possible that this could lead to some significant additional economic benefits.

At this time we are not in a position to quantify the specific impact of these corrections on the overall benefit/cost ratio or to determine whether the ratio would come out above or below unity if these corrections were made.

We end with a comment based on the US experience with large water projects. The key economic fact about these projects is that most of their costs are fixed costs. Consequently, if there is any unanticipated demand shortfall, costs decline less than revenues and profit suffer. When this happened with the Central Arizona Project (CAP), the project managers attempted to compensate by raising the price charged to urban water agencies, but the urban users balked and threatened to reduce the amount of water they would take from project.¹⁷ The CAP managers found themselves trapped in a vicious circle. Given a shortfall in sales, they had a smaller base of water sales from which to recover their fixed costs. When they raised water rates, this discouraged demand and created an even greater shortfall in sales. In the end, with CAP, general tax revenues were required to bail the project out.

We are concerned that the Ebro River project might face some similar financial risks. This is why we have stressed the importance of conducting careful and detailed marketing studies to verify the real extent of the market for project water. There is an immediate need for (1) a convincing financial plan that will ensure the generation of revenues in the amount and with the timing required to ensure that the project is a financial success, and (2) firm contracts (or their equivalent) with the intended agricultural and urban users of project water committing them to pay an appropriate portion of the capital costs of the project, so that they share with the Spanish government some of the financial risks associated with this large capital investment.¹⁸

habitat protection constituted the main component of environmental benefits (Wegge, Hanemann and Loomis, 1996).

¹⁷ They actually had fewer alternative options than the urban users of water from the Ebro River project because the urban areas in Arizona are located inland and have no access to desalinated seawater.

¹⁸ This was done in California with the financially successful State Water Project (SWP). At the outset of the SWP, the prospective users signed contracts committing them to cover the project's capital costs. With the federal government's Central Valley Project, by contrast, contracts were not negotiated with the users until after the main construction had been completed; this failure to secure a financial commitment from intended users in advance of construction has contributed significantly to the subsequent financial troubles of the CVP.

APPENDIX 5D: WATER RESOURCE

WATER RESOURCES FINDINGS AND RECOMMENDATIONS

BY: JOHN A. DRACUP & EDWARD MEANS

5.1. Construction of on-line vs. off-line regulatory storage reservoirs and dams

The construction of additional upstream on-line reservoirs in the Ebro River basin is not needed for the transfer of water out of the basin. Some additional storage is recommended in this technical review but, based on the Californian experience since 1970, such storage should be located downstream of the diversion in an off-line area (usually a dry canyon or similar area with low wildlife value).

We believe that it is advantageous to the Plan to provide regulatory storage for the water that is being diverted from the Ebro River to the Jucar and the Segura regions of south-eastern Spain. Storages of this type are useful to store water during surplus flows to be released during later low flow conditions. This regulatory storage is usually provided by traditional on-line dams, which are common throughout the world. Traditional on-dams transverse across natural rivers and streams, causing environmental degradation such as the displacement of people living in the upstream inundated area, the blockage of migrating fish, and the trapping of sediment that normally would be carried down the river and replenish coastline beaches. In contrast, off-line dams are defined as storage facilities that are not built across a natural stream or river but are constructed in an area where there is a minimum of environmental degradation and impact on the ecology. These facilities are usually built as pump-storage facilities. That is, water is pumped into these reservoirs from a nearby lake or canal during off-peak energy demand hours, i.e., 6 pm to 12 noon. Water, when needed, is returned to the supply source during the peak energy hours of 12 noon to 6 pm. Peak electrical energy in the U.S. is worth three to six times the off peak energy.

Two examples of off-line reservoirs in California are the Los Banos detention dam and reservoir that is located in the San Joaquin River basin. The facility, which is owned and operated by the California State Department of Water Resources is part of the California State Water Plan that moves water from the Feather River in the northern Sacramento River basin southward through the San Joaquin Valley to Southern California. Built in the 1960's this storage facility provides water storage, hydroelectric power, and recreation opportunities such as boating and fishing.

The second example of off-line reservoirs is the newly constructed Diamond Valley Lake that is located in Southern California. The reservoir was developed via the construction of two earth filled dams across the ends of two parallel ranges of hills. This facility provides an emergency water supply for Southern California during times of drought or disruption of service due to earthquakes. This 800,000 acre-foot (~ 1,000 hm³ or approximately the volume to be diverted from the Ebro River) reservoir is owned and operated by the Metropolitan Water District of Southern California, which is a purveyor of water to approximately fifteen million people on the Southern California coastal plain. The Diamond Valley Lake is pump-storage facility and provides off-line storage of water, peak hydropower, and recreational opportunities.

Finding: The document entitled “ACT 10/2001, on the 5th of July, on the National Hydrological Plan” (hereafter cited as the NHP) contains in ANNEX II List of Investments the names of numerous on-line dams that apparently may be built as part of this plan. They are mostly on-line dams in the Ebro River basin tributaries designed for water supply and irrigation within the Ebro watershed. Construction of these reservoirs upstream of the proposed diversion and within the Ebro River basin is not part of the out-of-basin transfer that is the mandate of the US Technical Review Team.

Recommendation: The U.S. Technical Review team recommends that the potential of off-line regulatory storage dams and reservoirs be studied in suitable areas of the Jucar and the Segura regions. These out of basin, downstream dams are not alternatives to existing dams on the Ebro River itself. The out of basin reservoirs could be an important regulatory storage mechanism since they could be located close to the demand centers. In addition, out-of-basin storage has the potential to provide peak hydroelectric power generation and water based recreation such as boating and fishing.

5.2. Establishment of a government research foundation

The construction of a large scale water transfer project such as proposed by the Spanish Government for the transfer of the waters of the Ebro River to the Jucar and Segura regions of southeast Spain provides an unique opportunity for significant research studies to determine whether or not this project may cause long term environmental impacts on a range of ecosystems. An example of a similar research endeavor in the U.S. was the long term Lake Powell project that studied the impacts of the Glen Canyon Dam and it's reservoir, Lake Powell, on the environment of the Colorado River canyon.

This proposed research study would first establish a baseline of environmental indicators. Of particular importance is the monitoring and recording of current ground water levels in unconfined aquifers, the current area and extent of sea water intrusion into coastal aquifers, the flora and fauna along the route of the proposed canal and surrounding environs, the current ecological condition of the coastal wetlands along the route of the canal, and the current ecological condition of the Ebro River delta. Such a research study should be comprehensive, broad in scope, and funded from the present to at least ten years after the completion of the project.

Finding: The Ebro water transfer plan provides the Spanish Government an excellent opportunity to provide funding for significant extended research in the areas of hydrology, ecology, and the environmental sciences.

Recommendation: A well-funded SNHP research foundation be established for the purpose of funding university and private research endeavors aimed at understanding the ecological and environmental changes that result from this large-scale project.

5.3. Uncertainty concerning the impacts of global climate change on the Ebro River transfer plan.

The phenomena of global climate change could have a significant impact of the SNHP and particularly the river basin deltas and coastal regions of Spain. In spite of current levels of uncertainty and controversy concerning global climate change there is an agreement among knowledgeable scientist world wide that: (1) the amount of greenhouse gases such as carbon dioxide is increasing in the atmosphere; (2) the world

wide atmospheric temperature has increased approximately $\frac{1}{2}$ degrees Celsius (0.6 +/- 0.2 degrees Celsius) during the 20th century; and (3) and, most important to the Ebro River transfer plan, the average world wide sea level rise has been approximately 12 centimeters (an average of 1 to 2 mm) during the 20th century. Furthermore, as stated in the Assessment of the Intergovernmental Panel on climate Change (IPCC 2001), "globally it is very likely that the 1990s was the warmest decade, and 1998 was the warmest year, in the instrumental record (1861-2000)."

However, when reviewing various reported impacts of global climate change one should keep in mind that this phenomena is presented via three different approaches: (1) the changes that are recorded in the current geophysical record; (2) the changes that are predicted from General Circulation Models (GCM's); and (3) the changes that are determined from various assumed scenarios of the impacts of global climate change. Each of these impact-reporting techniques will now be discussed in some detail. The changes that are currently reported in the geophysical record are the most reliable assuming accurate measuring devices are available for recording the data. Reliable indicators of global climate change include changes in air and water temperature, changes in the volume of glaciers and icy regions, sea level rise, etc. The changes that are predicted from the 22 GCM's located at research facilities around the world are based on the results from these complex digital simulation models. Attempts by these 22 GCM's to reproduce current regional climatology have produced mixed results. For example, the reproduction of precipitation in California by the 22 GCM's results in such diverse values that they cannot be used for operational hydrology at their current level of development. Due to the wide range of possible predictions of global or regional climate change based on assumed scenarios, the third approach mentioned above, have limited use for operational purposes.

The three parameters of global climate change that possibly may have the greatest impact on Spain are air temperature changes, sea level rise, and changes in annual runoff. Based on prediction from seven GCM's, the IPCC reports that there is a potential air temperature change ranging from a low of 2 degrees Celsius to a high of 4.2 degrees Celsius by the year 2100. Based on the predicted sea level rise from seven different GCM's, the IPCC reports a potential global range 0.2 to 0.82 meters increase by the year 2100 (IPCC 2002). Based on two versions of a GCM, the IPCC reports that the region of Spain south of the Pyrenees Mountains could experience a 0 to 25 decrease in annual runoff in mm per year by the year 2050. However, the important flow generation area of the Pyrenees Mountains could experience a significant decrease of 50 to 150 mm per year of runoff by the year 2050 (IPCC 2002).

The White Paper on Water in Spain (2000) discusses the impact of global warming on the water supplies in Spain in Section 3.1.8.2, pages 173-179. This White Paper is basically correct and is in agreement with the IPCC reports that there will be a decrease in streamflow in Spain due to global climate warming.

Finding: The impact of global climate change based on increases in air temperature, sea level rise, and annual runoff potentially could be a significant problem and have negative impacts on the planning and management of water resource systems in Spain.

Recommendation: That water resource managers in Spain keep abreast of predictions of global climate change that might impact their water resource system. Water resource

planners and policy makers should keep abreast with the latest global climate change findings of the IPCC and the U.S. NOAA assessments reports via their web sites.

5.4. Establishment of a metered ground water wells.

In Section 17 of the NHP, Uses of transferred water, number 1 (d), it is stated the transferred water will be used to restore over-exploited aquifers. Furthermore, in number 5 of Section 17, states “the governing board of the Water Authorities...shall study the hydrological balance, and ...establish the territorial area affected”.

Finding: There seems to be no discussion in the documents on how the authorities will physically recharge the ground water basins and stop the over-exploitation of the groundwater aquifers by enforcing the stoppage of pumping in the effected areas.

Recommendation: It is recommend that the NHP include a comprehensive environmental monitoring plan, which will establish the current levels of ground water in the Segura and the Jucar basins. Furthermore, the wells need to be monitored via a metering system. An enforcement policy and or a monetary penalty needs to be delineated to ensure the stoppage of the continued pumping of water from over-exploited aquifers.

5.5. Monitoring the potential extension of irrigated areas

In Section 17 of the NHP, Uses of transferred water, number 2, it is stated that the “transferred water cannot be used to create new irrigated land, nor to extend existing irrigated land...” Furthermore, in number 7 of Section 17 is it stated the “Council of Ministers, shall lay down the different uses, area, and applications zones...” However, there is no discussion on how the authorities will enforce the ban on the extension of irrigated areas.

Finding: There seems to be no discussion in the literature concerning the procedure that will be used to eliminate the expansion of irrigated area in the receiving basins of the Segura and the Jucar.

Recommendation: It is recommended that the NHP include an environmental monitoring plan which will establish the current spatial extend of the irrigated areas in the Segura and the Jucar basins. Furthermore, an enforcement policy and or a monetary penalty need to be established to ensure the stoppage of the expansion of irrigated areas in the receiving basins. Remote sensed data from satellites may be appropriate for this task.

APPENDIX E: BIBLIOGRAPHY & REFERENCES

HYDROLOGY

Plan Hidrológico Nacional-Análisis de Sistemas de Recursos Hidráulicos, Septiembre 2000.

ECOLOGY

- Araujo, R., and M. A. Ramos. 2001a. Life-history data on the virtually unknown *Margaritifera auricularia*. P. 143-152, In: G. Bauer and K. Wachler (eds.) *Ecology and Evolution of the Freshwater Mussels Unionoida*. Springer Verlag.
- Araujo, R., and M. A. Ramos. 2001b. Action plans for *Margaritifera auricularia* and *Margaritifera margaritifera* in Europe. *Nature and Environment*, No. 117. 64 p.
- Araujo, R., Bragado, E., and M. A. Ramos. 2001. Identification of the river blenny, *Salaria fluviatilis* as a host to the glochidia of *Margaritifera auricularia*. *J. Molluscan Studies* (Malacological Society of London). 67:128-129.
- Bachand, P. A. M. & A. J. Horne. 2000a. Denitrification in constructed free-surface wetlands I. Very high nitrate removal rates in a macrocosm study. *Ecological Engineering* 14: 9-15.
- Bachand, P. A. M. & A. J. Horne. 2000b. Denitrification in constructed free-surface wetlands II. Vegetation community effects. *Ecological Engineering* 14:17-32.
- Balada, R. 2000. Past, present and future of the Ebro Delta Park. *Medi ambient, tecnologia i cultura*. 27:1-9.
- Beutel, M. W. & A. J. Horne. 1999. A review of the effects of hypolimnetic oxygenation on lake and reservoir water quality. *J. Lake & Reservoir Management*. 15: 285-297.
- Casamayor, E. O., Garcia-Cantizano, J., Mas, J., and C. Pedros-Alio. 2001. Primary production in estuarine oxic/anoxic interfaces: contribution of microbial dark CO₂ fixation in the Ebro River Salt Wedge Estuary. *Marine Ecology Progress Series*. 215:49-56.
- Comin, F. A. 1999. Management of the Ebro River Basin: Past, Present and Future. *Water Sci. Tech.* 40(10): 161-168.
- Comin, F. A., Alonso, M., Lopez, P., and M. Comelles. 1983. Limnology of Gallocanta Lake, Aragon, northeastern Spain. *Hydrobiologia*. 105:207-221.
- Comin, F. A., Martin, M., Meneendez, M., Romero, J. A., and J. A. Herrera-Silveira. 1995. Integrated management of a coastal lagoon in the Ebro Delta. Proceedings of the 2nd Internat. Conf. On the Mediterranean Coastal Environment. *MEDCOAST* 95 p. 883-895.
- Comin, F. A., Romero, J. A., and C. Garcia. 1998. Removal of nitrogen and phosphorus from agricultural sewage in two restored wetlands. *Verh. Internat. Verein. Limnol.* 26:1316-1320.
- Elvira, B. 1995. Native and exotic freshwater fishes in Spanish river basins. *Freshwater Biology*. 33:103-108.
- Fleming-Singer, M. S. & A. J. Horne. 2002. Enhanced nitrate removal efficiency in wetland microcosms using an epi-sediment layer for denitrification. *Environ. Sci. Technol.* 36: 1231-1237.
- Gracia, V., Jimenez, J. A., and A. Sanchez-Arcilla. 1995. Nearshore profiles along the Ebro Delta coast. Implications for coastal processes. Proceedings of the 2nd Internat. Conf. On the Mediterranean Coastal Environment. *MEDCOAST* 95 p. 1131-1143.

- Grande, C., Araujo, R., and M. A. Ramos. 2001. The gonads of *Margaritifera auricularia* (Spengler, 1793) and *M. margaritifera* (Linnaeus, 1758) (Bivalvia: Unionoidea). *J. Molluscan Studies* (Malacological Society of London). 67:27-35.
- Horne, A. J. & C. R. Goldman. *Limnology*. McGraw-Hill, New York, 2nd Edition, 1994. 576 pp.
- Horne, A. J. 1997. The use of wetlands in promoting water reuse for water and wildlife. Proceedings: *Merging our Resources*, Univ. California Water Reuse Program, Monterey, June 1997. 11 pp.
- Horne, A. J. 2000. Potential for wastewater treatment and high quality water production using wetlands in the desert southwest. Rept. For Black & Veatch, Las Vegas. March 2000. 21 pp.
- Horne, A. J. 2000. Phytoremediation by Constructed Wetlands. Pp. 13-60 in N. Terry (Ed.) *Phytoremediation of Contaminated soil and Groundwater*. CRC Press. Boca Raton, Florida.
- Horne, A. J. Potential value of constructed wetlands for nitrate removal along some large and small rivers. *Ver. Int. Ver. Limnol.* 27: 4057-4062.
- Horne, A. J. 2000. Testimony on the water shortages and endangered sucker fish kills in Upper Klamath Lake, Oregon. Given before the Subcommittee on Water and Power, Senate Committee on Energy and Natural Resources. Washington DC. March 21, 2000 (3 p + expanded document on restoration of the lake ecosystem).
- Ibanez, C., Day, J. W., Canicio, A., Prat, N., and A Curco. 1995. The Ebro Delta, Spain: water and sediment management in the context of relative sea level rise. Proceedings of the 2nd Internat. Conf. On the Mediterranean Coastal Environment. *MEDCOAST* 95 p. 809-826.
- Ibanez, C., Pont, D., and N. Prat. Characterization of the Ebre and Rhone estuaries: A basis for defining and classifying salt-wedge estuaries. *Limnol Oceanogr.* 42:89-101.
- Ibanez, C., and N. Prat. 1996. Changes in the hydrology and sediment transport produced by large dams on the lower Ebro River and its estuary. *Regulated Rivers: Research and Management*. 12:51-62.
- Ibanez, C., Escosa, R., Munoz, I., and N. Prat. 1991. Life cycle and production of *Ephoron virgo* (Ephemeroptera: Polymitarcidae) in the Lower River Ebro (NE Spain). P. 483-492, In: J. Alba-Tercedor and A. Sanchez-Ortega (eds.) *Overview and Strategies in Plecoptera and Ephemeroptera*. The Sandhill Crane Press.
- Ibanez, C., Rodrigues-Capitulo, A., and N. Prat. 1995. The combined impacts of river regulation and eutrophication on the dynamics of the salt wedge and the ecology of the lower Ebro River (North-east Spain). P. 105-114, In: D. M. Harper and A. J. D. Ferguson (eds.), *The Ecological Basis for River Management*. John Wiley.
- Jennings, G. 1996. *European freshwater fishes*. A fifteen-language reference index. London: Calypso Publications. 77 p.
- Jimenez, J. A., Capobianco, M., Suanez, S., Ruol, P., Fraunie, P., and M. J. F. Stive. 1995. Proceedings of the 2nd Internat. Conf. On the Mediterranean Coastal Environment. *MEDCOAST* 95 p. 827-840.
- Lopez, M. A. 2001. Macrobentos. Especies indicadoras: *Margaritifera auricularia*. P. 149-164, In: N. Prat y C. Ibanez (dirs.) *El Curso Inferior del Ebro y su Delta*. Marzo 2001.
- Lopez, M. A., y A. Sostoa. 2001. Comunidades piscícolas en el tramo final del río Ebro. P. 167-187, In: N. Prat y C. Ibanez (dirs.) *El Curso Inferior del Ebro y su Delta*. Marzo 2001.

- Lopez, M. A., y A. Sostoa. 2001. Comunidades piscícolas en el tramo final del río Ebro. P. 167-187, In: N. Prat y C. Ibanez (dirs.) *El Curso Inferior del Ebro y su Delta*. Marzo 2001.
- Maitland, P. S. 1991. Conservation of the threatened freshwater fish in Europe. *Nature and Environment*. No. 46. 76 p.
- Mitsch, W. J., A. J. Horne & R. W. Nairn. 2000. Nitrogen and phosphorus retention in wetlands – ecological approaches to solving excess nutrient problems. *Ecological Engineering* 14: 1-7.
- Munoz, I., and N. Prat. 1989. Effects of river regulation on the lower Ebro River (NE Spain). *Regulated Rivers: Research and Management*. 3:345-354.
- Munoz, I., and N. Prat. 1994. Macroinvertebrate community in the lower Ebro river (NE Spain). *Hydrobiologia*. 286:65-78.
- Munoz, I., and N. Prat. 1994. Macroinvertebrate community in the lower Ebro river (NE Spain). *Hydrobiologia*. 286:65-78.
- Padro, A. 1996. Conservation strategies for the natural river bank groves of the middle Ebro valley in Spain. *UN-FAO Forest Genetic Resources*. 23:1-6.
- Palanques, A., and J. Guillen. 1995: The Ebro Delta coastal change: natural and human factors. *Proceedings of the 2^d Internat. Conf. On the Mediterranean Coastal Environment. MEDCOAST 95* p.897-909.
- Plans, M. 2001. Macrobentos. Especies indicadoras: *Ephoron virgo*. P. 137-145, In: N. Prat y C. Ibanez (dirs.) *El Curso Inferior del Ebro y su Delta*. Marzo 2001.
- Prat, N., and C. Ibanez. 1995. Effects of water transfers projected in the Spanish National Hydrological Plan on the ecology of the lower River Ebro (N.E. Spain) and its delta. *Water Sci. Tech.* 31(8):79-86.
- Prat, N., Munoz, I., Camp, J., Comin, F. A., Lucena J. R., Romero, J., and M. Vidal. 1998. Seasonal changes in particulate organic carbon and nitrogen in the river and drainage channels of the Ebro River (N.E. Spain). *Verh. Internat. Verein. Limnol.* 23:1344-1349.
- Ramsar Convention on Wetlands. 2000. Ramsar Advisory Missions: No. 43, Ebro Delta, Catalonia Spain. English Summary.
- Reilly, J. F., A. J. Horne & C. D. Miller. 2000 Nitrogen removal in large-scale free-surface constructed wetlands used for pre-treatment to artificial recharge of groundwater. *Ecological Engineering* 14:33-47.
- Rodo, X., Baert, E., and F. A. Comin. 1997. Variations in seasonal rainfall in Southern Europe during the present century: relationships with the North Atlantic Oscillation and the El Niño-Southern Oscillation. *Climate Dynamics*. 13:275-284.
- Sabater, S., and I. Munoz. 1990. Successional dynamics of the phytoplankton in the lower part of the river Ebro. *Jour. Plankton Res.* 12(3):573-592.
- Sanchez-Arcilla, A., and J. A. Jimenez. 1994. Breaching in a wave-dominated barrier spit: the Trabucador Bar (north-eastern Spanish Coast). *Earth Surface Processes and Landforms*. 19:483-498.
- Sanchez-Arcilla, A., Jimenez, J. A., Gracia, V., and H. I. Valdemoro. 1995. Sediment budget at the Ebro Delta coast: a multiscale approach. *Proceedings of the 2^d Internat. Conf. On the Mediterranean Coastal Environment. MEDCOAST 95* p. 769-779.
- Sanchez-Arcilla, A., Jimenez, J. A., Stive, M. J. F., Ibanez, C., Prat, N., and J. W. Day, Jr. 1993. Impacts of sea-level rise on the Ebro Delta: An approach. *Proceedings of the 1st Internat. Conf. On the Mediterranean Coastal Environment. MEDCOAST 93* p. 1103-1117.
- Sanchez-Arcilla, A., Jimenez, J. A., Stive, M. J. F., Ibanez, C., Prat, N., Day, J. W. Jr., and M. Capobianco. 1996. Impacts of sea-level rise on the Ebro Delta: a first approach. *Ocean & Coastal Management*. 30(2-3):197-216.

- Sostoa, A. & F. J. Sostoa. 1985. The fish communities of the Ebro delta (northeast Spain): a model of Mediterranean estuarine ecosystem. P. 79-126, In: A. Yanez-Arancibia (ed.), *Fish community ecology in estuaries and coastal lagoons: Towards an ecosystem integration*. Mexico: UNAM Press.
- Sostoa, A., & J. Lobon-Cervia. 1989. Fish and fisheries of the river Ebro: Actual state and recent history. P. 233-247, In: G. E. Petts (ed.), *Historical change of large alluvial rivers: Western Europe*. John Wiley.
- Tola, J., y Infiesta, E. 2002. *Pescos continentales de la península Ibérica*. Madrid: Ediciones Jaguar. 215 p.
- Zahradnik, J., y J. Cihar. 1981. *Guía Básica de la fauna de Europa*. Barcelona. Ediciones Omega, S. A., 390 p.

ECONOMICS

- Hanemann, W. Michael. 2002. *The Central Arizona Project*, Working Paper No. 937, Department of Agricultural & Resource Economics, UC Berkeley, October 2002.
- Holland, Stephen P. & Michael R. Moore, "Cadillac Desert Revisited: Property Rights, Public Policy and Water resource Depletion." *Journal of Environmental Economics and Management* (forthcoming)
- William E. Martin, Helen Ingram & Nancy K. Laney. 1982. "A Willingness to Play: Analysis of Water resources Development," *Western Journal of Agricultural Economics*, 1982, pp 133-139
- McMahon Paul & Meg Postle, 2000. "Environmental Valuation and Water Resources Planning in England and Wales," *Water Policy*, 2: 397-421.
- Ministerio de Medio Ambiente, 2002. *Strategic Assessment of the National Hydrological Plan: Summary Document*. January.
- Ministerio de Medio Ambiente. 2000. *Plan Hidrológico Nacional: Análisis Económico*. Madrid, September.
- Ministerio de Medio Ambiente. 1998. *Libro Blanco del Agua en España*.
- US General Accounting Office. 1996. Bureau of Reclamation - Information on Allocation and Repayment of Costs of Constructing Water Projects (GAO/RCED-96-109)
- Richard W. Wahl. 1989. *Markets for Federal Water: Subsidies, Property Rights and the Bureau of Reclamation*. Resources for the Future,
- Thomas C. Wegge, W. Michael Hanemann & John Loomis. 1996. "Comparing Benefits and Costs of Water Resource Allocation Policies for California's Mono Basin." In Darwin C. Hall (ed) *Advances in the Economics of Environmental Resources Volume 1: Marginal Cost Rate Design and Wholesale Water Markets*. Greenwich, CT: JAI Press.
- Paul N. Wilson. 1997. "Economic Discovery in Federally Supported Irrigation Districts: A Tribute to William E. Martin and Friends," *Journal of Agricultural and Resource Economics*, pp. 61-77.

WATER RESOURCES

- Cabezas, F., 2002, Sustainability of Groundwater Use, Internal Report, Ministry of the Environment, Madrid, Spain.
- Day, Kathleen, 2002, Comments on the analysis of the National Hydrological Plan, the EIA presented by the Spanish authorities in January 2002, the Hydrological Plan for the Ebro River Basin and the proposed National Irrigation Plan, including the report that accompanied these. Unpublished European Union report.

Intergovernmental Panel on Climate Change, 2001, Climate Change 2001: Synthesis Report.

Spanish Government, 2001, ACT 10/2001, of the 5th of July, on the National Hydrological Plan.

Spanish Ministerio De Medio Ambiente, 2002, Strategic Environmental Assessment of the National Hydrological Plan, Summary Document, January.

U.S. Army Corps of Engineers, 2000, Planning Guidance, ER 1105-2-100, Washington D.C., April 22nd.

APPENDIX F:

SHORT RESUMES OF THE US TECHNICAL REVIEW TEAM

SHORT RESUME	Dr. ALEX J. HORNE, Professor of Ecological Engineering, University of California, Berkeley
EDUCATION:	Ph.D. 1969. University of Dundee, Scotland: Limnology & Oceanography. B.Sc. 1964 University of Bristol, England: Biochemistry (Chemistry & Zoology)
EXPERIENCE	Dr. Horne has been the professor of Ecological Engineering at the Department of Civil & Environmental Engineering at the University of California since 1971. He teaches two popular undergraduate courses on the Ecology & Management of Wetlands & Rivers and Lakes & Reservoirs as well as graduate courses in Aquatic Restoration, Research Methods & Ethics. Initial research on algae in lakes, oceans, and wetlands in four continents included the first studies on the eutrophication of Clear Lake California (1970-78). He is an expert in biological and chemical aspects of water and aquatic management including pollution in lakes, reservoirs, wetlands, rivers, streams, estuaries and the open ocean. He has studied lakes, reservoirs, streams, wetlands and oceans in Africa, Antarctica, Alaska, Europe, Australia, Asia, N. & S. America. He has been a university Principal Investigator in over 70 funded research projects and a consultant in over 500 water-related projects in California, Nevada, Arizona, Oregon, Washington, Colorado, Florida, New York, as well as Canada, Taiwan, Central America, Australia & UK. He has been involved in the design and operation of all California Water Project reservoirs and conveyance facilities since 1972 & has studied & testified on the Project including ecological effects in the Sacramento-San Joaquin River Delta & the San Francisco Bay Estuary. Areas of specialty include: toxicity & biostimulation of domestic, industrial, & agricultural waste waters on animals & plants in lakes, reservoirs, wetlands, rivers, estuaries, coastal waters & deep oceans. Environmental effects of large-scale ocean thermal power plants using cold, deep nutrient-rich cooling water with surface disposal. Sewage, oil, heavy metal & selenium pollution. Water reuse and wetlands for heavy metal and nutrient removal. In situ pollution monitoring with bivalves & attached algae. Eutrophication & algal nuisance control in freshwater lakes, rivers, & estuaries. Effects of urban runoff. Design & management of drinking water and recreational reservoirs, taste & odor & algal toxicity problems. Recent projects include large & small constructed wetlands for wastewater treatment and drinking water in S. California and Los Vegas, copper in urban runoff, pathogen removal from recreational beaches, reservoir oxygenation for fish health & eutrophication reversal, TOC/DOC and taste & odor reduction in reservoirs, farmers versus water quality solutions, restorations of San Francisco Bay-Delta, Mountain Lake (San Francisco), Lake Elsinore (S. Calif.), Newport Bay-estuary (S. Calif.), Upper Klamath Lake (Nevada) & saline Walker Lake, Nevada.
PROFESSIONAL AFFILIATIONS : PUBLICATIONS	24 scientific societies in water-related areas in the US and Europe. Associate Editor for <i>Journal of Lake & Reservoir Management</i> . ~ 200 publications in major scientific and engineering journals & reports including the world's best selling textbook on <i>Limnology</i> (the study of lakes, ponds, reservoirs, wetlands, rivers, streams & estuaries).

SHORT RESUME	Dr. JOHN DRACUP, Professor of Environmental Engineering, University of California, Berkeley
EDUCATION:	Ph.D. 1966. University of California, Berkeley: Civil Engineering (major in water resource engineering & hydrology, minor in agricultural economics) M.S. 1960. Massachusetts Institute of Technology, Cambridge, Civil Engineering B. S. 1956. University of Washington, Seattle, June, Civil Engineering
EXPERIENCE	Dr. Dracup has been a professor in Civil & Environmental Engineering at Berkeley since 2001. Prior to that he was a professor in the equivalent department at the Los Angeles campus since 1965. At Berkeley he teaches undergraduate courses in Fluid Mechanics and the Design of Environmental and Water Resource Systems, and graduate courses on Water Resources Planning and Management and Global River Basins in Conflict. The focus of his research program is in the areas of hydrology and water resource systems analysis. In the area of hydrology he has been involved in the stochastic analysis of floods and droughts and the assessment of the impact of climate on hydrologic processes. In the area of water resources interests are in the simulation and optimization of groundwater systems and large-scale river basin systems. He has been a Principal Investigator for research grants from the United Nations Development Program, the National Science Foundation, the Ford Foundation, the Office of Naval Research, the Environmental Protection Agency, the Office of Water Resources Research, the California Air Resources Board, the Metropolitan Water District of Southern California, the U.C. Water Resources Center, the U.C. Pacific Rim Research Center and the National Institute for Water Resources Research.
PROFESSIONAL AFFILIATIONS :	Registered Professional Civil Engineer: California # C 22128. His is a Fellow of four and a member of six professional societies. He has been a member of seven National Research Council panels. Previously Associate Editor for <i>Water Resources Research</i> , <i>Journal of Hydrology</i> , & <i>Journal of Hydrologic Engineering</i>
PUBLICATIONS	~ 100 Publications in major hydrology and water resource journals.

SHORT RESUME	Dr. MICHAEL HANEMANN, Chancellor's Professor of Agricultural and Resource Economics and Public Policy, University of California, Berkeley.
EDUCATION:	Ph.D in Economics, Harvard University, 1978. M.Sc in Economics, London School of Economics, 1967. B.A. in Philosophy, Politics and Economics, Oxford University, 1965.
EXPERIENCE	Dr. Hanemann teaches and researches on water resource economics, the economics of environmental policy, non-market valuation, and decision analysis. He has lead developments of revealed preference and stated preference methods of non-market valuation; now also widely used in market research. In 1986 he was retained by the California State Water Resources Control Board to serve as its economics staff to analyze the economic and financial impacts of regulating agricultural drainage discharges to the San Joaquin River in the Grasslands area. He then served as the Board's economics staff for the first three years of its Hearings on water diversions from the San Francisco Bay/Delta to central and southern California. He subsequently participated in the negotiations which led to the signing of the Memorandum of Understanding on Urban water Conservation. From 1992 to 1994, he was senior economic consultant to the Board for its Environmental Impact Report on Mono Lake, and conducted the analysis of the economic impacts of reduced diversions on Los Angeles' water supply, on outdoor recreation in the Mono Basin, and on statewide public-trust (nonuse) values associated with the protection of Mono Lake. In 1992 he served as Technical Adviser to the Mayor of Los Angeles' Blue Ribbon Committee on Water Rates. In 1993 he served as a consultant on water rates, demand forecasting, and integrated resource planning for a Blue Ribbon Task Force established by its Board of Directors to review the Metropolitan Water District of Southern California. His work on water rate setting has received considerable attention in the California water industry, and he has co-authored several reports on water pricing and conservation for the California Urban Water Conservation Council. Since 1988 he has served as a consultant to NOAA and the Attorneys General of California, Alaska, Montana and New York with regard to litigation for natural resources damages for from oil spills and other toxic releases. In 1993-94, he was a consultant to the US Environmental Protection Agency in preparing the regulatory impact analysis of the proposed water quality standards for the San Francisco Bay/Delta with responsibility for estimating the impacts on urban water use in Southern California, commercial fishing, and water-based recreation in Northern California. He was subsequently a consultant for the Bureau of Reclamation's Programmatic EIS for the Central Valley Improvement Act. Since 1993 he has conducted research funded by the National Institute of Global Environmental Change on economic aspects of climate change impacts on water resources in California.
PROFESSIONAL AFFILIATIONS:	He currently serves as a member of the EPA Science Advisory Board Environmental Economics Advisory Committee and the CALFED Urban Drinking Water Quality Advisory Committee. He served on the National Research Council's Committee to Evaluate the Glen Canyon Environmental Studies Program and the NRC Committee on Wolf and Bear Hunting in Alaska.
PUBLICATIONS	Over 100 journal articles, technical reports and books.

SHORT RESUME	Dr. IGNACIO RODRIGUEZ ITURBE, Professor of Environmental Sciences, Princeton University
EDUCATION:	Ph.D.,Colorado State University.Civil Engineering with major in Hydrology,1967 M.Sc.,California Institute of Technology,Civil Engineering with major in Hydraulics,1995.
EXPERIENCE	Civil Engineer,Universidad del Zulia,Maracaibo ,Venezuela,1993. Dr.Rodriguez has been a professor of Civil and Environmental Engineering at Princeton since January 1999 where he holds the Theodora Shelton Pitney chair in environmental sciences.Before that he was a Distinguished Professor at Texas A&M and previously taught at MIT and the Universidad Simon Bolivar (Caracas).His area of expertise is surface hydrology where he has published several books and near 200 papers.He has been a Principal Investigator for numerous grants of the National Science Foundation,NASA and other organizations.Dr.Rodriguez has carried out extensive international consulting in a broad range of topics related to surface hydrology.These include hydrologic analyses for dam design and operation,water supply systems,multiple objective water developments,flood control,irrigation needs,etc,etc.His consulting has taken place in several countries of South America,Europe and the United States.
PROFESSIONAL AFFILIATIONS : PUBLICATIONS	American Geophysical Union,American Meteorological Society,Colegio de Ingenieros de Venezuela,U.S. National Academy of Engineering Several books and near 200 papers.

SHORT RESUME	MR. EDWARD G. MEANS III, Senior Vice President, McGuire Environmental Consultants, Inc.
EDUCATION:	B.A., University of California, Irvine, California (Honors 1977) M.A., University of California, Irvine (1980) Professional Management Program, Graduate School of Business Administration, University of Southern California (1987)
EXPERIENCE	Mr. Means is Sr. Vice President of McGuire Environmental Consultants. Expertise includes water quality management assessments, development & implementation of long-range utility water resource, quality and management strategies/plans. He provides services to water utilities in the areas of regulatory compliance including the Microbial/Disinfection By-Products (M/DBP) rule cluster, the Arsenic rule, the Radon rule, and the Groundwater rule. The Firm's client list includes over 70 public and private water utilities, numerous law firms, private corporations and non-profit corporations. Projects Mr. Means has managed for the firm over the last 3 years include: • California Avocado Commission & S. California grower representation in strategic agricultural water supply & water rate issues • Principal Investigator for AWWARF 2604, "A Strategic Assessment of the Future of Water Utilities". Published book entitled "Watercourse: Charting Your Utility's Future" • Principal Investigator for AwwaRF 2816, "Water Quality Management: How to Structure It in a Utility" • Provided Seattle Public Utilities strategic planning assistance • Developed and conducted workshop to develop water quality strategic plan for East Bay Municipal Utilities District • Provided American Water Works Services Company strategic planning assistance • Power generation: provided consulting services to energy companies regarding availability of cooling water supplies • Invited speaker on water utility management and strategic issues • Project Manager managing technical assistance to Orange County Water District on control strategies for NDMA in recycled water • Project Manager; marketing opportunities for excess water quality laboratory capacity for Irvine Ranch Water District In Mr. Means' prior experience includes 18 years in various capacities at the Metropolitan Water District of Southern California. As Chief Operating officer for the largest U.S. water utility serving 17 million residents of the coastal plan of Southern California, he had responsibility for all business aspects including capital programs, operating budgets, water rates, and water resources planning.
PROFESSIONAL AFFILIATIONS :	16 scientific societies/organizations in water management & policy. Chair, Exec. Comm. WUC of AWWA. Disinfection By-Products; Co-Chair Assoc. Metropolitan Water Agencies (NWRA) Water Quality Comm. (1992); Chair AWWARF Pathogen Detection Workshop. 1992; Co-Chair NWRA Safe Drinking Water Act Reauthorization Task Force (1992, 1993); Scientific Planning Comm. 1999 ILSI Safety of Water Disinfection Conf.; 1998; California-Nevada Section AWWA George Warren Fuller Awardee 2000; California-Nevada Section Trustee
PUBLICATIONS	Available on request

SHORT RESUME	DR. JAMES C. ROTH, Independent Consultant, San Francisco, California.
EDUCATION:	B.S., Biology. University of Wisconsin-Oshkosh, 1961 M.S., Zoology/Limnology, Virginia Polytechnic Institute, 1963 Ph.D., Limnology/Fisheries, University of Michigan, 1971
EXPERIENCE	Dr. Roth's specialties are in limnology & oceanography: biology&ecology of freshwater, estuarine & marine invertebrates & fish; aquatic entomology; zooplankton, phytoplankton, zoobenthos & fish ecology; laboratory/field experimentation on aquatic systems; design & execution of programs to evaluate effects of wastewater discharges to aquatic environments; aquatic ecosystem management. Dr. Roth is currently an Ecological Consultant. He was Associate Research Ecologist (Sanitary Engineering and Environmental Health Research Laboratory, University of California, Berkeley, 1982-89), Marine Biologist (Ocean Thermal Energy Conversion Program, Lawrence Berkeley Laboratory, University of California, Berkeley 1979), Research Associate (Tahoe Research Group, University of California, Davis, 1977), Research Associate (Clear Lake Algal Research Unit, Lakeport, California 1976-78). Assistant Professor, (Department of Biological Sciences, University of California, Santa Barbara 1973-1974). Assistant Research Limnologist (Great Lakes Research Division, University of Michigan 1971-1973).
PROFESSIONAL AFFILIATIONS :	11 national & international societies including the American Society of Limnology and Oceanography, California Lake Management Society & Pacific Estuarine Research Society
PUBLICATIONS	78 publications and reports. Details available on request.