CARTOGRAPHIC EVALUATION OF ENVIRONMENTAL MANAGEMENT STRATEGIES*

Jonathan C. Goyert
Karen L. Daniels
Rodney H. Strand
Michael P. Farrell

Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, TN. 37830

ABSTRACT

A complex problem in environmental research is the evaluation of the effects of various environmental management strategies at regional, ecosystem, population and community levels. The large amount of data generated in these evaluations needs to be presented in a form that allows decision makers at state or federal levels to knowledgeably act on the information. A series of computer-generated maps with increasing levels of resolution can be used to summarize these data and more clearly illustrate the potential effects of various decision alternatives.

A number of graphic displays are presented to illustrate how policy decisions concerning California water allocation can affect salinity distribution and aquatic plant communities in San Francisco Bay. The graphic displays include: 1) a vendor-supplied coordinate map for the regional level, 2) a bench-digitized coordinate map for the ecosystem level, and 3) a program-generated coordinate map for the community level.

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INTRODUCTION

The evaluation of environmental management strategies is often difficult because policy decisions made at the State or Federal level may adversely affect regional, ecosystem, population and community level parameters. When making policy decisions, a resource manager needs to evaluate a number of different factors including which spatial scales to consider and what environmental parameters to evaluate within each scale. To adequately understand the relationship between a policy decision and its ultimate effect on various environmental parameters requires the collection, analysis and evaluation of a large amount of data. In the past, the sheer mass of data generated in these types of investigations often discouraged a logical approach to the decision making process. These data need to be reduced to a more manageable size and displayed so that the resource manager can digest and act on the information more efficiently and knowledgeably.

Scientists at Oak Ridge National Laboratory (ORNL) are currently developing new techniques of visual data analysis through the use of computer generated graphics (Strand and Farrell 1980, Farrell and Strand 1980, Vansuch et al. 1980, Waterhouse et al. 1981). A series of highly detailed maps of varying scale can be produced by these techniques which enable a resource manager to examine the effects of alternative management strategies at increasingly finer levels of resolution. These maps present a clearer picture of the geographic areas potentially affected by management alternatives and the range of environmental responses that can be expected. Since cartographic applications are, by nature, site-specific, the type of displays required for a particular problem depends on the scale of resolution desired by the resource manager. This paper presents a number of ORNL's cartographic display methodologies using a hypothetical water resource problem in California as an example.

BACKGROUND

The state of California has a water distribution problem. Northern California receives over 2 to 3 times as much rain as central and southern California (Olson et al. 1980). The California water project was developed by state and federal agencies to divert water from northern to southern California via two aqueducts located in the Central Valley. Increased diversions to southern California for farming and municipal uses have reduced the amount of water remaining for inflow to the San Francisco Bay-Delta system. The water resource manager must balance flows between northern and southern California so that agricultural interests in the Central Valley are satisfied while water quality and aquatic habitats in the San Francisco Bay-Delta are preserved. For this paper, the effects of 2 water management alternatives on 4 environmental responses will be evaluated. Alternative 1 would allow 5 million acre-feet of water to be diverted to southern California while alternative 2 would increase this amount to 10 million acre-feet. The four factors representing regional, ecosystem, population and community level responses in California are: 1) total crop production in the Central Valley, 2) San Francisco Bay-Delta salinity distribution, 3) Suisun Bay and Delta striped bass distribution and abundance, and 4) Suisun marsh macrophyte production.

METHODS

All maps presented in these examples were produced on a TEKTRONICS MODEL 4662 interactive digital plotter using the SAS/GRAPH GMAP procedure (SAS/GRAPH Users Guide 1981). Two SAS data sets are required to produce a map with this procedure: 1) a map data set which contains a series of X and Y coordinates for designating a unit area and an identification (ID) value for labeling each unit area; and 2) a response data set containing values for environmental factors for each unit area and their corresponding ID values. Map data sets were produced in three ways: 1) using the cartographic files provided with the 1981 release of SAS/GRAPH, 2) using a coordinate system obtained by digitizing an existing map, and 3) using SAS programming statements to generate a series of X and Y coordinates.

Example 1 illustrates the regional distribution of total crop production in California's Central Valley under both alternative water management strategies (Figure 1). The response data for alternative 1 were obtained from ORNL's Geoecology Data Base (Olson et al. 1980) for the year 1975. Alternative 2 data were generated from the 1975 data by assuming a 25 % increase in crop production for those counties in the Central Valley that would benefit by the additional water allocation. The coordinates for California's county boundaries were obtained from the SAS/GRAPH cartographic file named COUNTIES. The following SAS statements created the map data set used in example 1:

```
DATA MAPIN; SET USMAP.COUNTIES;
IF STATE=06;
PROC GPROJECT DATA=MAPIN OUT=MAPOUT;
ID COUNTY;
```

The IF statement subsets the COUNTIES file to include just those counties in the state of California. The GPROJECT statement applies the Albers conical projection method to the data set obtained from the COUNTIES file. The crop production data set was combined with the map data set using the following program statements which are typical of the GMAP statements used throughout this paper:

```
PROC GMAP DATA=CROPS MAP=MAPOUT;
ID COUNTY;
CHORO YIELD / DISCRETE;
FORMAT YIELD YIELDFMT.;
LABEL YIELD='CROP YIELD';
PATTERN1 V=E;
PATTERN2 V=M1N45;
PATTERN3 V=M3N45;
PATTERN4 V=M1X45;
PATTERN5 V=M3X45;
PATTERN6 V=S;
```

The scale of resolution is increased in the second example to illustrate the distribution of salinity in the Bay-Delta ecosystem under the two alternative strategies (Figure 2). The salinity data used for this example are on a station level and were obtained from the United States Geologic Survey (USGS) WATSTORE data base for the year 1978. The coordinates for the areas within the Bay-Delta were obtained by digitizing a USGS map using a TEKTRONICS MODEL 4956 digitizer. The X and Y coordinates may also be obtained by overlaying a grid on an existing map and retrieving the coordinates manually if a digitizer is unavailable. In this example, the San Francisco Bay-Delta was arbitrarily divided into 15 unit areas so that at least one station from the response data set was contained within each area. Each unit area was digitized separately so that an ID value could be assigned when the SAS map data set was created.

To further increase the scale of resolution, the map coordinate data set used for the salinity distribution displays can be subsetted to include only a portion of the estuary. A hypothetical distribution of young-of-the-year striped bass in the Suisun Bay and Delta under the two water management alternatives is generated and combined with the subsetted San Francisco Bay map coordinate data set to produce Figure 3.

The final example illustrates how the distribution of marsh macrophyte communities can change under the two water management alternatives (Figure 4). The scale of resolution has now increased to include only an 81 square meter part of Suisun marsh. The input data for this example were generated from an ORNL study of macrophyte distributions in freshwater experimental ponds. The data were adapted to conditions that may occur in a west coast marsh community. The map coordinates for this example were generated with the following SAS program statements:

```
DATA PLANTMAP;
DO J = 1 TO 9;
DO I = 0 TO 8;
LOC = I + 10*J;
X = J; Y = I; OUTPUT;
X = J + 1;    OUTPUT;
Y = I + 1;    OUTPUT;
X = J;        OUTPUT;
END;
END;
```

The four SAS OUTPUT statements in this program define the four coordinates of a square that the GMAP procedure uses to draw a single polygon and give it an ID value. The two DO statements are used to build a series of squares next to and on top of one another defining a grid with I by J dimensions.

RESULTS

The large amount of information collected and analyzed in these four diverse studies have been collapsed into 4 simple displays (Figures 1-4) for the resource manager to evaluate. In the first example, the regional distribution of total crop production in California's Central Valley under both alternative water management strategies was displayed (Figure 1). From these regional maps the water resource manager can easily see that over half of the Central Valley counties exhibit a significant increase in crop production under water management alternative 2. This increase in water flow will certainly benefit the farmers of the Central Valley and increase the overall crop production of California. The resource manager must now balance this increased agricultural production with any potentially adverse effects on those areas that would normally have received this water, the San Francisco Bay-Delta estuary.

The second example reveals that as additional water is diverted to southern California under water management alternative 2 the extent of salt water intrusion into the Bay-Delta, specifically Suisun Bay, increases (Figure 2). The resource manager realizes that this increase in Suisun Bay salinity could affect the distribution and abundance of both plants and animals in the area. The other parts of San Francisco Bay appear, however, to be relatively unchanged by the increased water transport under alternative 2. Based on these visual displays, the resource manager can now focus his attention on those areas most affected by the water management alternatives, i.e. Suisun Bay and Delta.

The third example demonstrates that both water management alternatives affect the distribution and absolute abundance of young striped bass in the Suisun Bay and Delta area (Figure 3). The apparent decrease in young striped bass abundance under water management alternative 2 may adversely affect the adult bass population. Striped bass are one of the major components of the sport fishery in the Bay-Delta and their decline may subsequently impact the regional economy by decreasing the number of fishing licenses sold, charter boats leased, fishing equipment retailed, etc., as well as a number of human quality of life values.

In the final example, the salt water movement up into Suisun Bay under water management alternative 2 has changed the marsh community from one dominated by freshwater and estuarine species (cat tails, alkali bulrush and pickleweed) to one dominated by the more salt tolerant species (cord grass and salt grass) (Figure 4). This alteration in marsh plant communities may subsequently affect the marsh animal communities and remove potentially valuable duck and other waterfowl habitat. As with the decrease in striped bass abundance, changes in the macrophyte communities under water management alternative 2 could adversely affect the recreational potential of the area, hunting equipment sales and other quality of life measures.

CONCLUSIONS

The cartographic analysis of these two water management alternatives demonstrates the usefulness of such an approach to a resource manager. All of the information contained in the four separate studies has been analyzed and condensed into 4 easily understood maps. Using this method of analysis, data interpretation is simplified and more readily understood, the range of possible effects on environmental parameters at various levels is illustrated, and a rapid comparison among alternative strategies is made possible. Equipped with the information provided by the various map displays, the water resource manager can now more knowledgeably decide which water management alternative is, on the one hand, most economically beneficial to the state of California and, on the other hand, least environmentally damaging.

Although this example evaluated the effects of only 2 alternatives and 4 factors, the method of analysis could easily be expanded to include a wider variety of both management alternatives and environmental factors. This evaluation may lead to other questions relative to environmental effects that can be evaluated with the same approach. The types of resource management questions illustrated in these examples are of concern to managers at all government levels. Managers at the local level may want to know how a particular management strategy affects their own particular area, whereas managers at the regional level are more concerned with establishing a state water policy that benefits the most people and results in the least environmental damage. If a state water management alternative cannot be demonstrated to be effective at the various levels of resolution through this type of analysis, then another strategy needs to be developed, analyzed and evaluated. The use of computer generated cartographics can assist the resource manager in this evaluation process.

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Figure 1. Annual crop yield (kg/ha)/ in California's Central Valley under two alternative water management strategies.

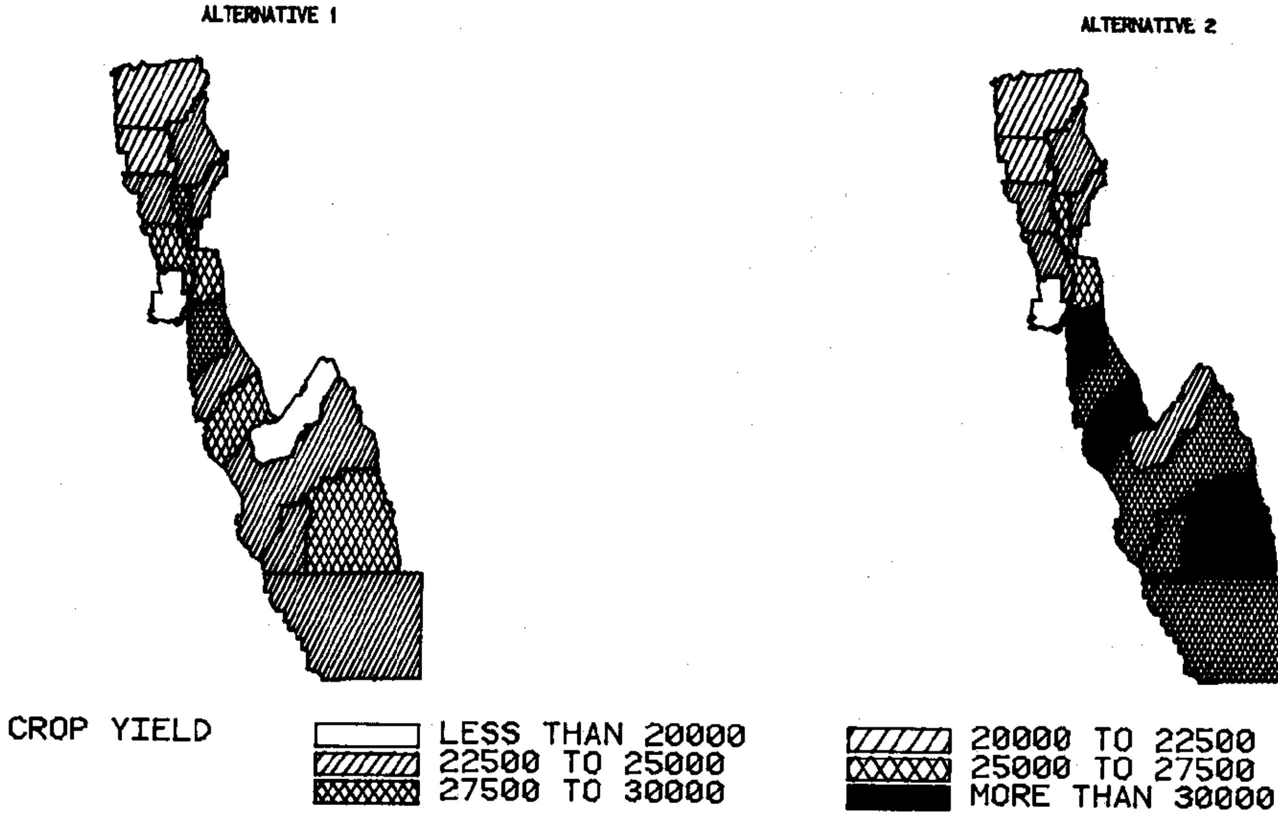

Figure 2. Salinity distribution in the San Francisco Bay-Delta under two alternative water management strategies.

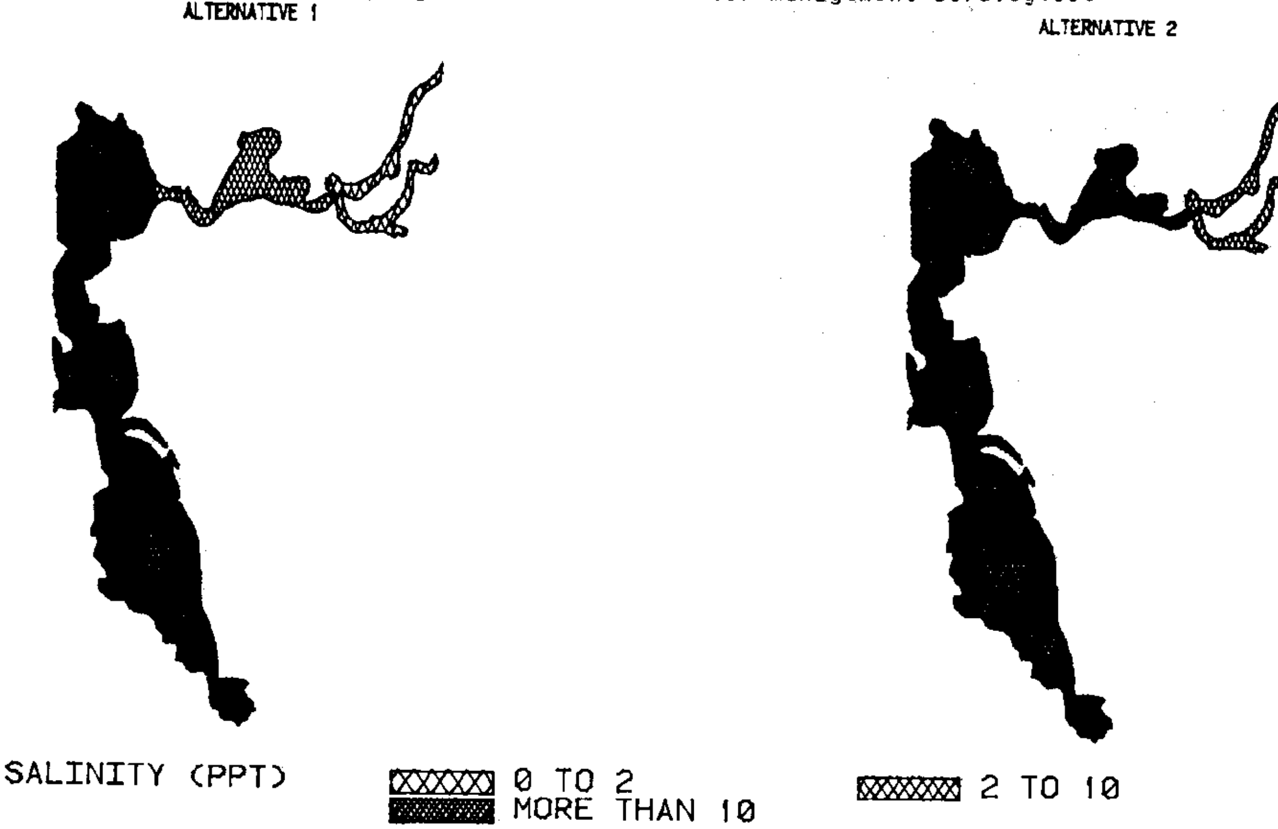

Figure 3. Striped bass distribution in Suisun Bay and Delta under two alternative water management strategies.

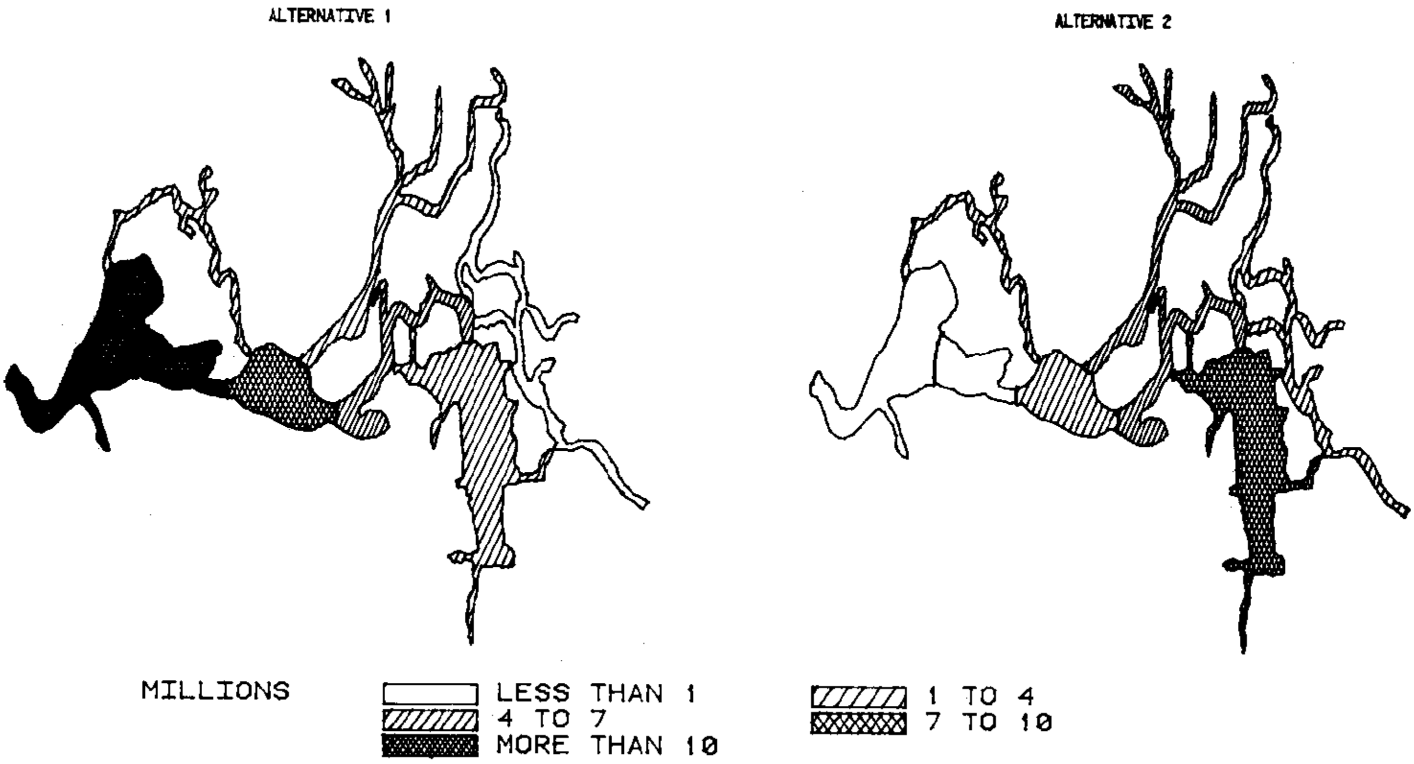

Figure 4. Marsh macrophyte distribution in Suisun Bay under two alternative water management strategies.