A Retrospective Analysis of GIS Performance: The Umatilla Basin Revisited

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ABSTRACT: This project evaluates the results of the 1982 geographic information system study entitled "The Columbia River and Tributaries Irrigation Withdrawals Analysis Project" by the U.S. Geological Survey's Earth Resources Observations Systems (EROS) Data Center and the U.S. Army Corps of Engineers, North Pacific Division. The specific research objectives of this paper are (1) to identify and delineate the spread of center pivot irrigation from 1979 to 1987; (2) to determine the degree of areal correspondence between the 1979 irrigation development potential map generated by GIS overlay analysis and a 1987 map of center pivot irrigation; and (3) to evaluate the effectiveness of the overlay analysis procedure utilized to create the irrigation potential map. The methodologies used to complete these objectives included interpretation of a 14 July 1987 Landsat TM false-color composite image, the transfer of information to a 1:250,000-scale USGS topographic map using a Zoom Transfer Scope, and the measurement of all center pivot irrigation lands for 1987. The change in area and location of center pivot irrigation was determined and compared to the 1979 predictive map of the potential for irrigation development.

INTRODUCTION

During the past decade there has been a proliferation of research studies concerned with the incorporation of remotely sensed data into Geographic Information Systems.[†] Many of these studies have focused on a Geographic Information System (GIS) approach to solving natural resource management problems (e.g., Lyon, 1983; Milne and Zhou, 1986; Hodgson *et al.*, 1987; Ferris and Congalton, 1989). Several have used distinct modeling techniques to illustrate possible outcomes of various management strategies or to highlight potential changes in resource utilization (e.g., Johnston, 1987; Agee *et al.*, 1989). Few, if any, researchers, however, have attempted to revisit a project site several years later in order to access the validity of their GIS analysis.

One of the earliest attempts to incorporate satellite imagery into a GIS for resource management was the Columbia River and Tributaries Irrigation Withdrawals Analysis Project (Johnson *et al.*, 1982; Loveland and Johnson, 1983). The Columbia River is the largest river flowing from the North American continent into the Pacific Ocean and is one of the world's greatest sources of hydroelectric power. It serves as the boundary between the states of Washington and Oregon and is an integral part of the Pacific Northwest Region. This region is greatly dependent on the Columbia River and its tributaries for power, navigation, water supply, recreation, and irrigation. Rapidly growing—and competing—demands on the river, however, made it necessary for the U.S. Army Corps of Engineers to review uses of the river and its tributaries, predict future uses and demands on the water resources, and develop a plan that would optimize multiple use in an effort to prevent a recurrence of the water shortages realized in 1977 after a severe drought.

To execute this plan, it was necessary to accurately document existing irrigation patterns and to anticipate the future water demand and potential development areas for irrigation. In 1979 a cooperative demonstration project was initiated between the U.S. Geological Survey's Earth Resources Observation Systems (EROS) Data Center and the U.S. Army Corps of Engineers, North Pacific Division. Their mission was to evaluate the role of satellite imagery and other spatial data for use in determining current irrigation patterns and the potential for irrigation development. Using GRID, a rudimentary grid-based GIS (Environmental Research Institute, 1982), information of past and present irrigation development in the Umatilla Basin and its impact on the Columbia River Basin was compiled. From these data, a map of potential irrigation development was generated detailing eight classes of suitability for future expansion of center pivot irrigation. The degree of areal correspondence between the spread of central pivot irrigation since 1979 and the map of potential irrigation development is the major concern of this research effort.

BACKGROUND

The 1979 Columbia River and Tributaries Irrigation Withdrawals Analysis Project was designed to determine the extent and impacts of current irrigation and the potential for future irrigation development (Johnson *et al.*, 1982; Loveland and Johnson, 1983). Accordingly, the following analysis objectives were defined:

- to determine the number of acres under irrigation from 1973 to 1979 and to find irrigation growth patterns;
- to determine crop types and irrigated land acreage in 1979;
- to estimate energy and crop water requirements for lands then under irrigation; and
- to identify those lands most suitable for future irrigation development.

Two sub-basins of the Columbia River Basin were chosen as project study areas: (1) the Yakima Basin which lies in Washington and (2) the Umatilla basin which lies in Oregon. The Yakima Basin was used as a control study site. Because of this, not all objectives were completed for this area and, therefore, a map of irrigation development potential was not generated. Only the Umatilla Basin was analyzed for irrigation development potential (Figure 1).

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†For the purposes of this paper, the term Geographic Information System refers to a family of geoprocessing software packages which are designed for the storage, manipulation, and retrieval of spatial data. Map processors (Pazner *et al.*, 1989) and map analysis packages (Tomlin, 1983) are included under this general definition.

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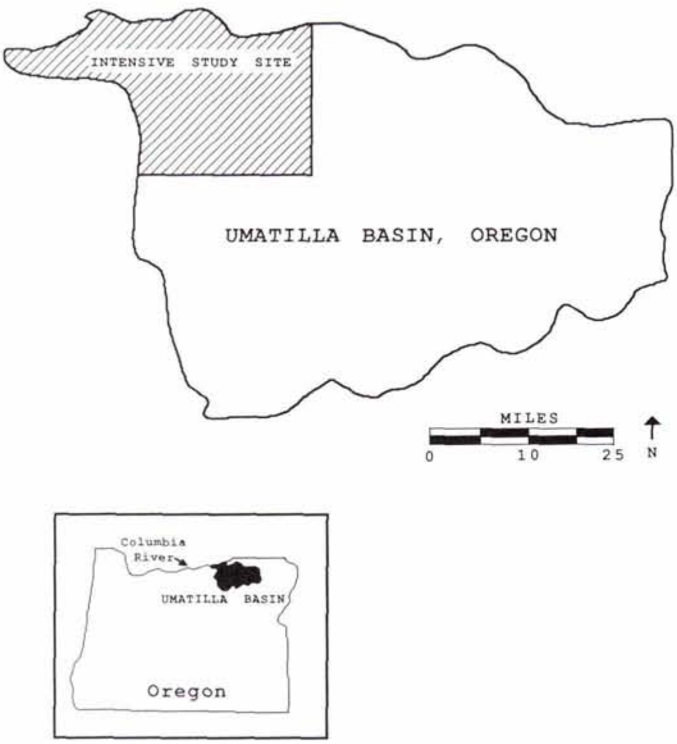

FIG. 1. Intensive study site of the Umatilla Basin.

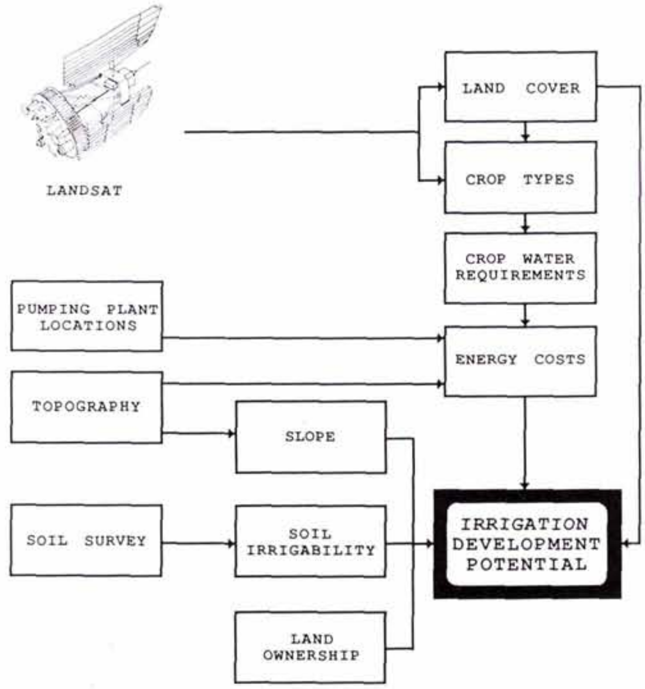

FIG. 2. Data inputs for model development.

The Umatilla Basin covers approximately 1.6 million acres in north-central Oregon and includes the urban areas of Umatilla, Hermiston, Stanfield, Echo, and Pendleton. The main crops include wheat, potatoes, corn, and alfalfa. Portions of the area were brought under towline sprinkle irrigation in the 1930s with average field sizes of approximately 80 acres. Within the basin, intensive irrigation covers only the northwest corner. Therefore, an intensive study site was chosen in this area to allow a better focus for the project (Figure 1).

Data inputs included Landsat MSS false-color composite images, pumping plant locations, topography, soil surveys, and land ownership. From these inputs, other spatial data were derived, such as slope, soil irrigability, land cover, crop types, crop water requirements, and energy costs (Figure 2). These inputs were supplemented with aerial photographs, ground truth data, and map-based ancillary data, and were digitally entered into a geographic data base.

A sequence of analytical tasks was then performed for the Umatilla Basin using these inputs to provide answers to the project objectives. The final project objective, the evaluation of irrigation development potential in the Umatilla Basin, was completed using a multivariable GIS overlay procedure (for a full description of the procedure, see Johnson *et al.* (1982) and Loveland and Johnson (1983)). Incorporated into the overlay procedure were the following assumptions developed jointly by scientists from the Corps of Engineers and the EROS Data Center:

- Energy costs had twice as much impact on potential irrigation development as any other factor.
- Physical characteristics, such as soils, slope, and land cover, all had equal weights in determining development potential.
- Land ownership was used only for land parcel elimination from consideration for irrigation development potential.
- Dryland agriculture lands were more favorable for irrigation development than rangelands.
- Water bodies, wetlands, urban areas, and forestlands were eliminated from consideration for irrigation development.
- Land slopes were considered as follows:

≤ 3	percent	most favorable
4–7	percent	less favorable
8–12	percent	least favorable
≥ 13	percent	non-irrigable.

- All soils were considered irrigable although they ranged from excellent to poor.

A second overlay procedure was then used for the actual modeling. This was done by summing the scores assigned to the weighted variables by grid cell to produce a composite score of irrigation potential. The cumulative cell scores were then evaluated and threshold scores were determined. Using these threshold scores, the raw scores were assigned to irrigation development categories (Table 1) and a final irrigation development potential map was produced (Plate 1).

OBJECTIVES

The specific research objectives of this paper are

- identify and delineate the spread of center pivot irrigation from 1979 to 1987;
- determine the degree of areal correspondence between the 1979 irrigation development potential map generated by GIS overlay analysis and a 1987 map of center pivot irrigation; and
- evaluate the effectiveness of the overlay analysis procedure utilized to create the irrigation potential map.

METHODS

In order to maintain consistency with the 1979 project, the same intensive study site was used (Figure 1). Results were then compared with the center pivot irrigation areas determined in the previous study.

To quantify the spread of central pivot irrigation in the intensive study site of the Umatilla Basin since 1979, lands under center pivot irrigation in 1987 were identified and mapped. Center pivot irrigation sites were defined by image color, size, shape, and location using Landsat TM false-color composite imagery. The image was acquired on 14 July 1987, the closest available date to the 26 July image date used in the 1982 project. Center

TABLE 1. CATEGORIES, SCORES AND FREQUENCY OF FUTURE IRRIGATION DEVELOPMENT AREA COMPOSITE.

Category	Composite Scores	Occurrence (Percent of Total Area)
Unsuitable	0-31	20
Poor	32-44	21
Fair	45-50	21
Good	51-53	19
Excellent	54-58	19

TABLE 2. CENTER PIVOT IRRIGATION ESTIMATED FOR THE UMATILLA BASIN STUDY SITE.

Year	Acres*	Percent Change From Previous Observation	Percent Average Annual Rate of Change
1973	19,424	–	–
1975	46,850	+141	+56
1977	59,246	+ 26	+13
1979	67,835	+ 14	+ 7
1987	94,065	+ 39	+ 4

* Calculated with correction factor of .79

pivot irrigation lands from this image were interpreted with a Zoom Transfer Scope and transferred to the Pendleton, Oregon-Washington (NL 11-7) 1:250,000-scale U.S. Geological Survey (USGS) topographic map (Plate 2). After the center pivot irrigation lands were mapped, the area was measured to determine the total area of center pivot irrigated lands in 1987 and the difference between the areal extent in 1979 and 1987.

In the 1979 project, center pivot irrigation area measurements were taken using an electronic area meter. Area measurements were then refined using aerial photographs in combination with the Landsat imagery in a double sampling procedure. Additionally, because actual irrigated area was only 79 percent of the grid cell area classified as center pivot irrigation, a correction factor of 0.79 was applied to the final estimates.

In the current project, neither an electronic area meter nor additional aerial photography were available to aid in acreage estimations. Instead, a dot grid area measurement technique was used. In order to ensure that the dot grid estimate would provide comparable acreage estimates, a dot grid estimate was completed on the 1979 center pivot irrigation areas. The double sampling procedure produced a corrected estimate of 67,835 acres. The dot grid method produced a corrected estimate of 67,302 acres, less than a one percent difference. For the purpose of determining center pivot irrigation growth trends, the dot grid method proved accurate enough to obtain comparable measurements of center pivot irrigation estimates.

DISCUSSION AND RESULTS

The increase of center pivot irrigation in the intensive study site of the Umatilla Basin can be seen in Figure 3 and Table 2. Total center pivot irrigation in July 1987 was estimated at 94,065 acres, an increase of 26,230 acres or approximately 39 percent over the 1979 figure of 67,835 acres.

During this period, annual growth rates increased, but at a decreasing rate. In 1975, there were 46,850 acres of center pivot irrigation. This corresponds to an average annual rate of increase from 1973 to 1975 of 56.0 percent. In 1977, there were 59,246 acres of center pivot irrigation, a 12.5 percent average annual rate of increase over 1975. In 1979, there were 67,835 acres of center pivot irrigation, with the average annual rate of increase falling to 7.0 percent from 1977. This trend of an increase at a decreasing rate continued through 1987 with the average annual rate of increase dropping to 4.2 percent.

The second and main objective of the study was to determine the areal correspondence between the 1979 irrigation development potential map (Plate 1) and the 1987 map of center pivot irrigation (Plate 2). The first step toward achieving this objective was to identify those areas which had been brought under center pivot irrigation since 1979. To do this, the 1979 and 1987 total center pivot irrigation area maps were overlaid. The difference between the two maps was noted on the Pendleton, Oregon-Washington 1:250,000-scale USGS topographic map.

The second step was to assign irrigation potential categories to the areas of irrigation growth defined above. The irrigation potential map included the following eight categories: (1) unsuitable, (2) poor, (3) fair, (4) good, (5) excellent, (6) existing irrigation, (7) urban areas, and (8) non-study. To determine which potential category the center pivot irrigation growth areas belonged to, the irrigation potential map was projected onto the USGS topographic map and a single irrigation category was assigned to each growth area (Figure 4). Each irrigation potential category area was then measured using the dot grid method.

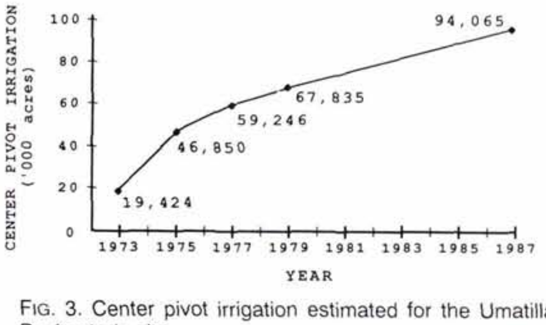

FIG. 3. Center pivot irrigation estimated for the Umatilla Basin study site.

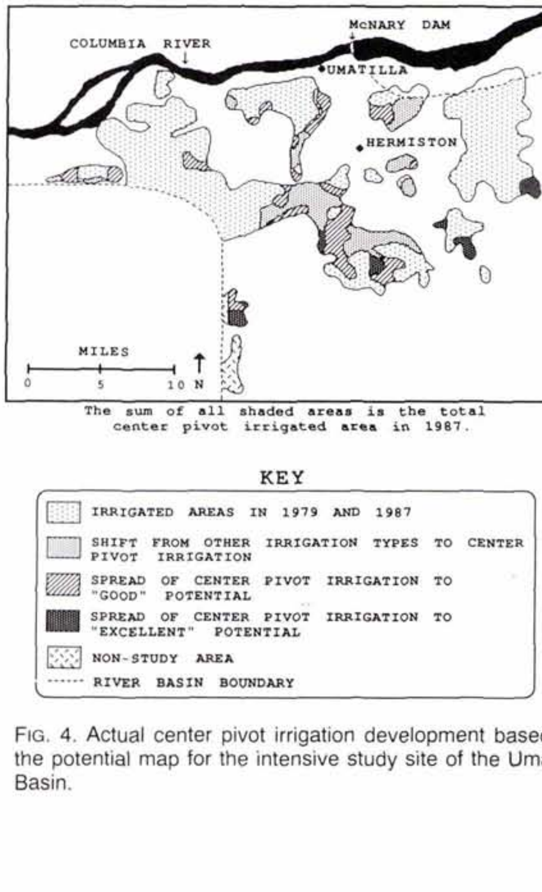

FIG. 4. Actual center pivot irrigation development based on the potential map for the intensive study site of the Umatilla Basin.

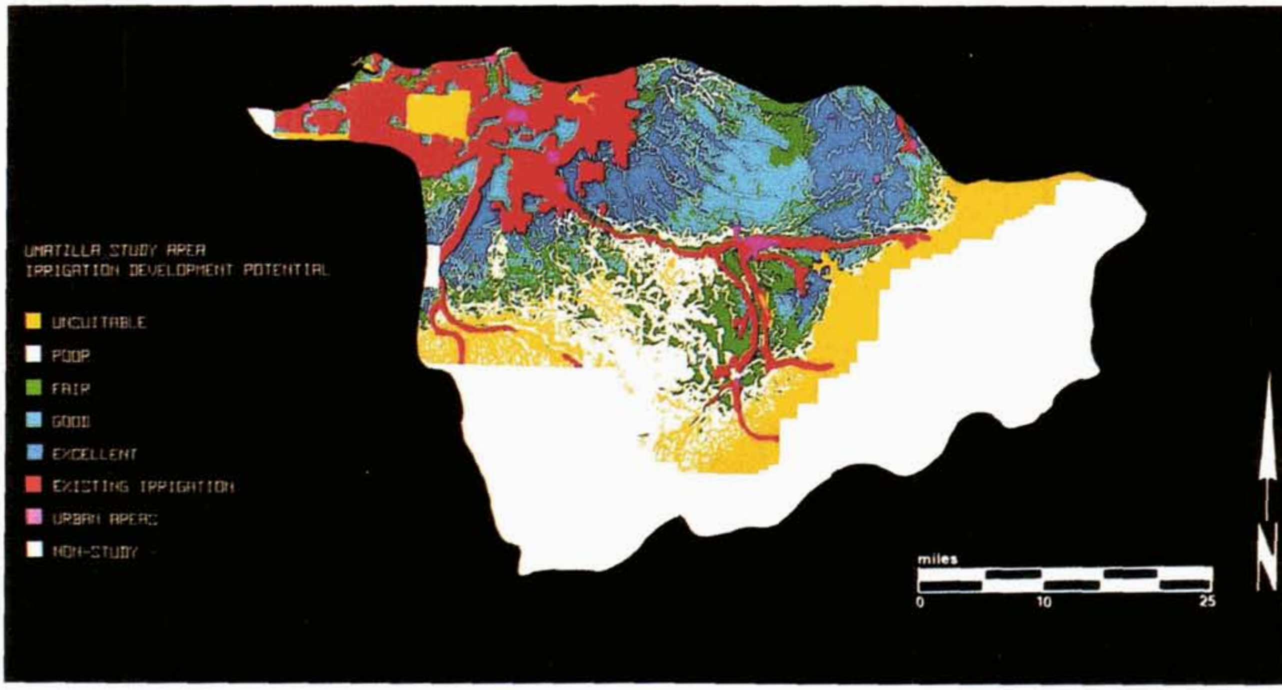

PLATE 1. Umatilla Basin irrigation development potential map. Source: Loveland et al., 1983.

PLATE 2. *Center pivot irrigation in the intensive study site of the Umatilla Basin in 1987.*

As seen in Table 3 and Figure 5, the largest center pivot irrigation expansion occurred as a shift from other irrigation types (such as towline) to center pivot, accounting for 12,713 acres or 47 percent of all growth. The second and third largest categories were seen to be an expansion of center pivot irrigation into areas classified as "good potential" at 9,249 acres or 34 percent and "excellent potential" at 3,039 acres or 9 percent of all center pivot irrigation growth. Ten percent of the growth areas were classified as "other". The "other" category consisted of those center pivot irrigation lands located in the river basin and included in the measured area, but were in the non-study area of the map of potential irrigation development.

CONCLUSIONS

The results of this study show a considerable slowing of center pivot irrigation expansion recently. There was a 39 percent increase from 1979 to 1987, amounting to 26,230 acres of new land brought under center pivot irrigation. It is these lands that were concentrated upon in order to determine how closely the Irrigation Development Potential Map (Plate 1) accurately portrayed which lands center pivot irrigation would most likely expand to in the intensive study site of the Umatilla basin.

The expansion of center pivot irrigation in the intensive study site was primarily to those areas that were already under other types of irrigation. Irrigation systems require land that is fairly level and uniform. The amount of capital necessary to bring crop land under center pivot irrigation is reduced significantly when the land is already under other forms of irrigation. Given the economic conditions facing the agricultural producer during these years, expansion into those areas was the least costly method of increasing center pivot acreage, explaining the 47 percent of total center pivot irrigation growth from 1979 to 1987 that shifted from other irrigation types.

The remaining 53 percent of center pivot irrigation growth was examined to evaluate the effectiveness of the GIS overlay analysis procedure utilized to create the irrigation potential map. As reported, 34 percent of the center pivot irrigation development spread to land rated as having "good" potential while 9 percent spread to those with "excellent" potential. There was virtually no spread to the "unsuitable," "poor," or "fair" categories. This would indicate that the assumptions and the geographic information system "predictive modeling" methodologies which formed the foundation of the overlay procedure used to generate the Irrigation Development Potential Map were sound. While the 1979 study could not have predicted the rate of center pivot irrigation development due to changes in farm and economic policies, the map did accurately predict those areas to which newly irrigated lands would most likely expand.

TABLE 3. CATEGORIES OF CENTER PIVOT IRRIGATION GROWTH FROM 1979 TO 1987 IN THE INTENSIVE STUDY SITE.

Category	Total Irrigated Acres*
Shift From Other Irrigation Types to Center Pivot Irrigation	12,713
Spread of Center Pivot Irrigation to "Good" Potential	9,249
Spread of Center Pivot Irrigation to "Excellent" Potential	2,401

* Calculated with correction factor of .79

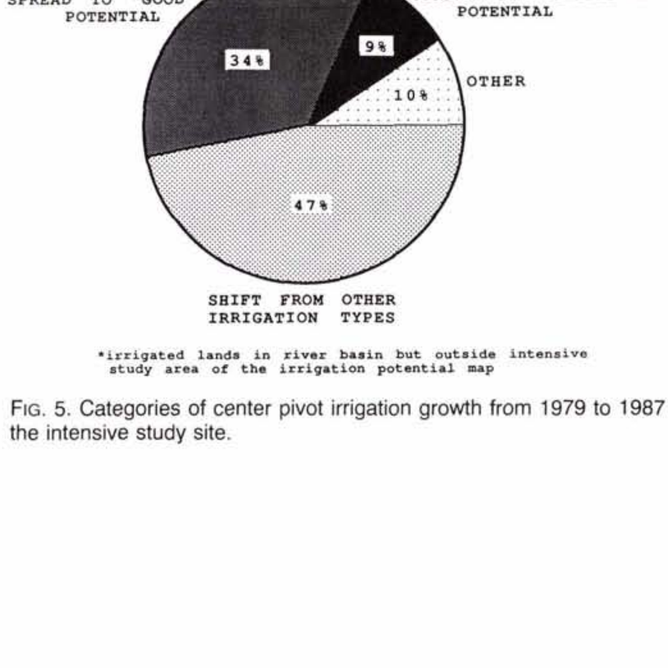

FIG. 5. Categories of center pivot irrigation growth from 1979 to 1987 in the intensive study site.

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