THOMAS R. LOVELAND
GARY E. JOHNSON†
Technicolor Government Services, Inc.
EROS Data Center
Sioux Falls, SD 57198

The Role of Remotely Sensed and Other Spatial Data for Predictive Modeling: The Umatilla, Oregon, Example*

The spatial and remotely sensed data provided a unique look at past, present, and future characteristics of irrigation development.

ABSTRACT: *The U.S. Geological Survey's Earth Resources Observation Systems Data Center, in cooperation with the U.S. Army Corps of Engineers, Portland District, developed and tested techniques that used remotely sensed and other spatial data in predictive models to evaluate irrigation agriculture in the Umatilla River Basin of north-central Oregon. Landsat data and 1:24,000-scale aerial photographs were initially used to map the expansion of irrigation from 1973 to 1979 and to identify crops under irrigation in 1979. The crop data were then used with historical water requirement figures and digital topographic and hydrographic data to estimate water and power use for the 1979 irrigation season. The final project task involved production of a composite map of land suitability for irrigation development based on land cover (from Landsat), landownership, soil irrigability, slope gradient, and potential energy costs.*

The methods and data used in the study demonstrated the flexibility of remotely sensed and other spatial data as input for predictive models. When combined, they provided useful answers to complex questions facing resource managers.

INTRODUCTION

THE U.S. GEOLOGICAL SURVEY'S Earth Resources Observation Systems (EROS) Data Center (EDC) has the responsibility to assist land and water resources planning and management agencies in using remotely sensed data as a tool to help solve inventory and analysis problems. EDC assistance has matured from the early Landsat era when the desired end product was commonly a land-use or land-cover map. Today, satellite-derived inventory data are routinely incorporated into geographic data bases and used in conjunction with other spatial data in models to provide answers to complex resource management questions. An example of this trend in resource analysis is a recently completed project involving EDC and the U.S. Army Corps of Engineers (COE), Portland District.

EDC and COE undertook a cooperative project in 1979–80 to explore the use of remotely sensed data in conjunction with other geographic data to assess several irrigation-related problems. The COE required information describing past and present measurements of irrigation and its impact in the Columbia River Basin and projections identifying lands suitable for future irrigation development. Specifically, the COE desired answers to the following questions:

*Presented at the Pecora VII symposium, Sioux Falls, South Dakota, 18–21 October 1981.

† Now with the Asian Regional Remote Sensing Training Center, Asian Institute of Technology, Bangkok, Thailand.

0099-1112/4908/-1183$02.25/0

- What is the growth rate of center pivot irrigation?
- How many acres of land were irrigated in 1979?
- What types of crops were irrigated and what were their acreages in 1979?
- What were the irrigation crop-water requirements in 1979?
- What were the irrigation energy requirements in 1979?
- Which lands are likely to be irrigated in the future.

To fill these information needs, a geographic data base was developed, and analytical methods were selected that would provide answers to these questions.

The project included two distinct components: (1) data base development and (2) predictive modeling. The data base development aspects involved analyzing remotely sensed data to inventory land cover and crop types and collecting cartographic data relating to irrigation development to create a digital geographic data base. The predictive modeling involved manipulating the appropriate data in various spatial models to provide measurements of resource (water and power) consumption and to identify potentially irrigable lands. The project methods were tested in the Umatilla Basin, Oregon, to determine their suitability for investigating irrigation in other parts of the Columbia River Basin. Figure 1 summarizes the analytical flow of the study.

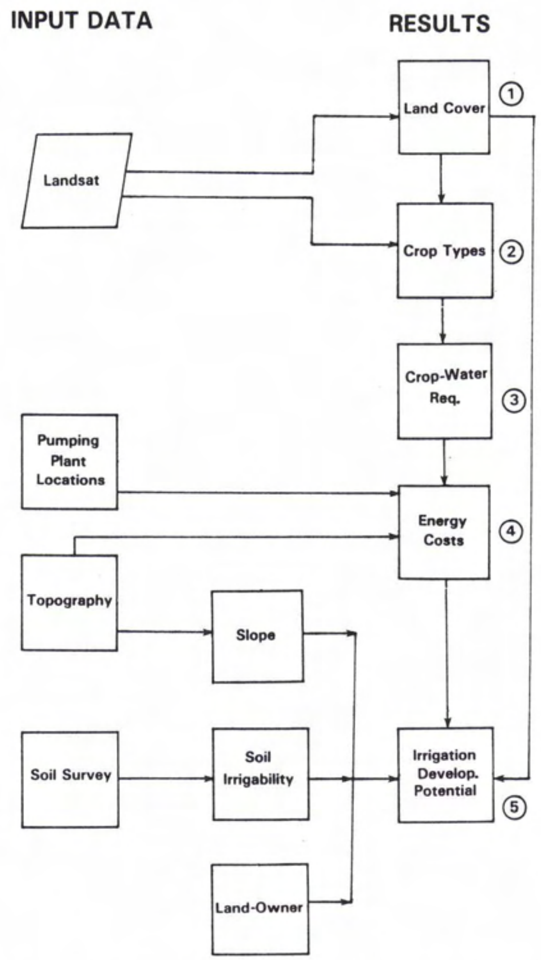

FIG. 1. Analysis sequence and spatial data used to assess Umatilla Basin irrigation.

STUDY AREA DESCRIPTION

The Umatilla River Basin occupies 1.6 million acres in north-central Oregon (Figure 2). The northern edge of the basin is bounded by the Columbia River. The Blue Mountains occupy the east and southeast regions. The Umatilla River flows through the center of the basin. The proximity of the Columbia River has contributed heavily to the ongoing development of irrigation in the area. The basin's first large irrigation project was the Umatilla Project developed near Hermiston, Oregon, by the U.S. Bureau of Reclamation in the 1930's. In the 1970's, much center pivot irrigation was developed adjacent to the Columbia River. The mixture of both old and recent irrigation development contributes to the complexity of the region. A wide variety of field sizes, shapes, irrigation methods, and crop types increases the difficulty of inventorying the region's irrigated land resources.

DATA BASE INPUTS

Data describing land use, physical terrain characteristics, and administrative boundary restrictions were entered into a digital geographic data base in order to address project topics (Table 1).

All data were stored in cellular form with 63.6-m^2 (1-acre) grid cells registered to a Universal Transverse Mercator (UTM) map projection. Digital inputs to the data base were incorporated using

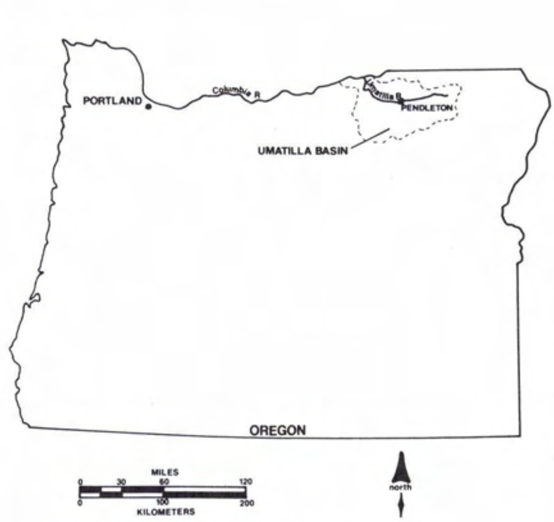

FIG. 2. Project study area.

TABLE 1. SUMMARY OF GEOGRAPHIC DATA BASE ELEMENTS.

Data Source	Input Form	Derivatives
Landsat	Photographic, digital	Land cover, crop type
Digital Terrain Tape	Digital	Elevation, slope
Soil survey	Map	Soil irrigability
Pumping plant location records	Tabular	Pumping distance
Administrative maps	Map	Land ownership

a least-squares registration process and resampling techniques appropriate to the characteristics of the data. Map inputs were digitized and georeferenced using an x-, y-coordinate digitizer.

REMOTE SENSING INPUTS

Landsat data, supplemented by 1:24,000-scale color-infrared aerial photographs, provided an inventory of 1973, 1975, 1977, and 1979 general land-cover patterns and 1979 irrigated crop type acreages. The remote sensing based inventory data were used for the measurement of the 1979 irrigation acreage, and the 1973–79 growth rate of center pivot irrigation, and the number of acres of specific types of crops irrigated in 1979. In addition, the inventories provided data elements needed to model current water and power consumption and to predict the areas of future irrigation development.

Land Cover Mapping. Maps of general land cover in the Umatilla Basin for 1973, 1975, 1977, and 1979 were produced by manual interpretation of Landsat false color composites (FCC's). A classification scheme comprised of the following Level I and III categories (Anderson *et al.*, 1976) was used:

- 100 Urban and Built-Up Areas
  - 211 Dryland Agriculture
  - 212 Center Pivot Irrigation
  - 213 Other (noncenter pivot) Irrigation
- 300 Rangeland
- 400 Forestland
- 500 Water Bodies
- 600 Wetlands

Using Landsat images obtained late in the irrigation season (late July through August), the land-cover catagories were readily mapped on the basis of their image color, size, shape, and location. This resulted in generalized maps displaying the dominant cover types in the basin. The final maps were interpreted with a minimum mapping unit size of 40 acres. With this resolution, it was possible to examine irrigation expansion rates and to determine the types of lands which had been converted to irrigation agriculture. The precise estimation of the number of irrigated acres was not possible, however, because the coarse resolution of the Landsat imagery precluded the mapping of small nonirrigated areas found within intensively irrigated regions. Color-infrared aerial photographs (1:24,000 scale) for 1979 were thus used with the Landsat images in a stratified double-sampling ratio-estimation process in order to provide refined estimates of the 1979 center pivot and other irrigation acreages (67,835 ± 6,960 and 62,679 ± 7,083 acres, respectively).

Table 2 summarizes the land-cover acreages measured directly from Landsat FCC's in this phase of the project. By comparing the 1973–79 acreage estimates, an annual center-pivot irrigation growth rate of 7,758 acres was estimated, with almost 56 percent of this acreage converted from dryland agriculture. The 1979 land-cover map was digitized and entered into the geographic data base. In digital form, the land-cover map provided stratification data needed to increase the efficiency of the crop-type analysis. It also provided data describing current land-cover patterns and irrigation conversion trends needed to assess the basin's irrigation development potential.

Crop Type Analysis. 26 July 1979 digital Landsat data were analyzed to produce a map and the initial acreage estimates of crop types irrigated in the Umatilla Basin. The use of digital data was considered advantageous for this problem since

TABLE 2. LAND-COVER ACREAGE ESTIMATES DERIVED THROUGH THE DIRECT MEASUREMENT OF LANDSAT FCC'S

Land-Cover Class*	Year			
	1973	1975	1977	1979
Center-pivot irrigation	24,587	59,304	74,995	85,867
Other irrigation	126,551	122,901	122,901	122,901
Dryland agriculture	553,187	527,681	518,646	512,423
Rangeland	419,577	413,197	403,452	402,711
Forestland	473,320	473,320	473,320	473,320

* Urban areas, wetlands, and water bodies were not shown because they occupied such a small percentage of the basin.

the spatial resolution of a 1.1-acre pixel provided more detailed information than is contained in a standard Landsat photographic image.

The crop classification process began with the geometric registration of the raw Landsat data into the data base. A least-squares registration using terrain control points and a nearest-neighbor resampling method were used to register the Landsat data to the 63.6-m^2 UTM referenced grid.

Because the irrigation in the Umatilla Basin was complex and variable, it was decided to stratify the Landsat data into analysis regions according to irrigation method. The digitized 1979 land-cover map was used as a mask to stratify two data sets—the center pivot stratum and other irrigation stratum—for classification. The use of a preexisting layer of the data base allowed narrowing and sorting of the Landsat data so that only the irrigable lands needed to be classified into crop-type categories, thus increasing analysis efficiency.

The crop types were classified independently for each of the two strata. A modified clustering technique (Fleming *et al.*, 1975) was used to define spectral class statistics, and a maximum likelihood algorithm was used to classify the two stratified data sets. Each stratum classification resulted in 18 spectral categories. The spectral classes were compared to field-collected crop reference data, and initial attempts were made to assign the spectral classes to crop-type categories. However, because of similar spectral characteristics existing between different crop types (particularly between wheat, alfalfa, and potatoes), only 60 percent of the data could be placed into the desired single-crop categories. This problem necessitated the use of detailed spectral class descriptions to describe the exact crop-type composition of each spectral class.* In this approach, a sampling technique was used to develop statistics describing the individual crop-type acreages represented by each of the 36 spectral classes for the two strata. The spectral classification and category descriptions were then incorporated into the geographic data base for subsequent use in estimating other characteristics of the basin's irrigation.

Tables 3 and 4 show the crop acreage descriptions of tbe spectral classes derived using a double-sampling procedure with the Landsat classification and field-collected crop data. The associated variance and standard error statistics were also estimated for each class. Plate 1 is the irrigated crop-type classification and general land-cover map for the Umatilla Basin. As stated previously, 60 percent of the irrigated croplands fall into single-crop categories. The usefulness of the remaining 40 percent that are in multicrop categories was salvaged by the development of detailed class descriptions that identify the specific characteristics of each spectral category.

* This approach is being used with increasing frequency as a means to provide useful information in areas where "pure" classifications are not possible (Rohde and Miller, 1981).

OTHER SPATIAL INPUTS

Digital Terrain Tapes. Digital Terrain Tape (DTT) data acquired from the U.S. Geological Survey's National Cartographic Information Center (NCIC) provided elevation values that could be used to further evaluate regional irrigation conditions. The elevation data contained on DTT's are based on digitized contour lines from U.S. Geological Survey 1:250,000-scale topographic quadrangles, with an interpolation algorithm used to estimate a regular spaced grid of elevations (U.S. Geological Survey, 1980). The data were considered to be useful only for regional analysis and not site-specific investigations.

The DTT data, because of their digital form, were easily incorporated into the data base. The elevation data were registered to the 63.6-m^2 grid cells and resampled using bilinear interpolation. The registered elevation values were then used to calculate the average percent slope between each cell and the adjacent cells.

Soil Survey Data. The detailed county soil survey for Umatilla County (Soil Survey Staff, 1948) and the preliminary soil survey for Morrow County were digitized for inclusion into the data base. The soil polygons were converted to 63.6-m^2 grid cells and stored in 158 soil mapping unit classes. Based on the chemical and physical characteristics of each soil mapping unit, each of the 158 classes was assigned to one of five soil irrigability categories (excellent, good, fair, poor, or unsuitable).

Land-Ownership. U.S. Army Corps of Engineers (1979) maps provided government land-ownership data. Corps maps were digitized, and the ownership polygons converted to a grid cell format.

Pumping Plant Locations. COE documents (Swan *et al.*, 1980) containing the locations of irrigation pumping plants along the Columbia River and its tributaries were used to establish a digital file of the locations of pumping plants. The pumping plant locations (identified by river-reach coordinates) were plotted on 7.5-minute quadrangle maps, digitized, and stored as point data.

PREDICTIVE MODELING

The inventory data derived through the interpretation of remotely sensed data, combined with the remaining spatial data contained in the digital data base, provided the elements needed to estimate 1979 irrigation water and power consumption and to identify the irrigation development potential of lands in the Umatilla Basin.

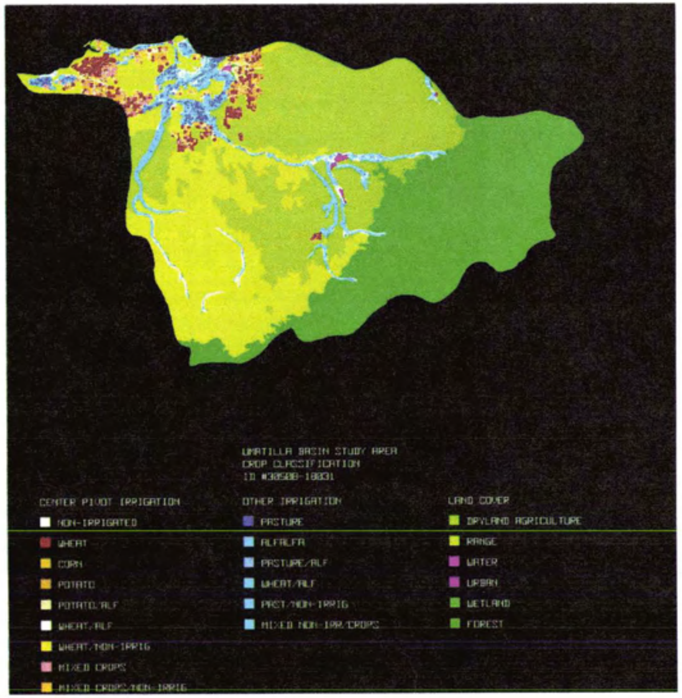

PLATE 1. 1979 irrigated crop-type classification and general land cover.

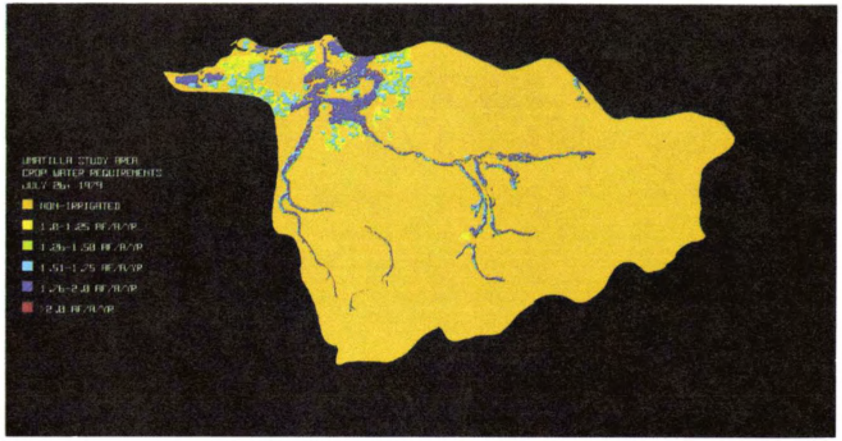

PLATE 2. 1979 irrigated croplands water requirements classification.

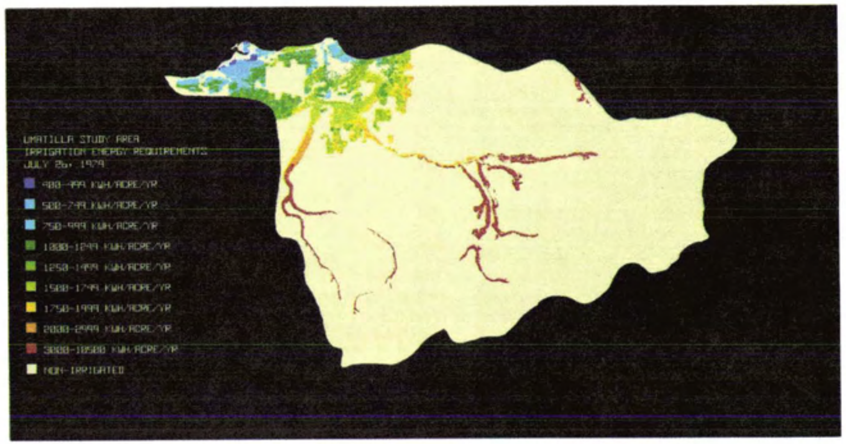

PLATE 3. 1979 irrigation energy requirements classification.

TABLE 3. CENTER-PIVOT STRATUM CROP ACREAGES BY SPECTRAL CLASS.

Spectral Class	Crop Type: Alfalfa	Corn	Potato	Wheat	Pasture	Peas	Beans	Mint	Onions
1	277	23	92	2,196	0	0	0	0	0
2	544	0	317	3,175	204	0	0	0	0
3	82	0	3,161	110	0	0	55	0	0
4	19	39	0	58	116	97	0	0	60
6	1,186	0	209	2,163	70	0	105	0	0
7	1,212	941	1,086	597	651	0	0	20	0
8	0	0	0	0	57	0	0	0	0
9	162	23	232	3,547	93	0	0	0	0
10	1,065	60	2,048	682	60	0	0	0	0
11	653	187	467	1,028	93	0	0	0	0
12	344	111	222	2,627	222	67	0	0	0
13	81	2,273	135	81	27	0	27	0	72
14	154	0	88	2,654	0	0	0	0	0
15	956	792	573	846	109	0	109	0	0
16	307	31	245	2,482	92	0	0	0	0
17	1,563	932	839	723	93	0	0	0	0
18	156	750	312	562	63	0	0	0	0
Total	8,761	6,162	10,026	23,531	1,950	164	296	20	132

PREDICTING CROP-WATER REQUIREMENTS

Estimates of 1979 irrigated crop-water requirements were calculated using the Landsat-based crop-type data and historic crop water requirement figures developed by the Soil Conservation Service (U.S. Soil Conservation Service, 1973) (Table 5). The specific water requirement per crop was multiplied by the area of each crop type found in each spectral class in order to determine the acre-feet of water required for each spectral class and overall. This simple translation of crop-type data to crop water requirements provided an estimate of 207,952 acre-feet of water needed for the basin's irrigation in 1979 and produced a file of spatial crop water requirements data. The 36-class crop water requirements classification is summarized in six categories and displayed in Plate 2.

It must be recognized that the analysis used water requirements figures based on an average of

TABLE 4. OTHER IRRIGATION STRATUM CROP ACREAGES BY SPECTRAL CLASS.

Spectral Class	Crop Type: Alfalfa	Corn	Potato	Wheat	Pasture	Beans	Mint	Straw-berries	Asparagus
1	101	0	0	505	0	0	0	0	0
2	1,335	0	157	0	786	157	0	0	157
3	1,496	0	0	0	45	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	1,270	0	868	68	1,804	201	467	0	668
6	412	0	0	0	0	0	0	0	0
7	697	0	620	154	3,756	0	39	0	77
8	1,856	0	53	212	4,030	0	106	53	0
9	133	0	927	88	2,207	0	88	0	221
10	697	131	218	0	6,135	0	87	0	0
11	0	0	0	0	51	0	0	0	0
12	3,923	0	531	200	2,261	67	665	133	67
13	1,021	0	34	0	5,205	0	0	0	0
14	1,422	414	432	1,483	494	0	0	0	0
15	1,518	0	34	0	2,624	0	207	0	0
16	716	0	0	1,312	119	0	0	0	0
17	1,814	209	35	0	391	0	107	0	0
18	2,058	0	105	53	2,553	0	369	0	0
Total	20,469	754	4,014	4,075	32,461	425	2,135	186	1,190

TABLE 5. HISTORIC CROP WATER REQUIREMENTS FOR UMATILLA BASIN CROPS (U.S. SOIL CONSERVATION SERVICE, 1973).

Crop Type	Water Requirements (acre-feet/acre/year)
Small grains	1.1
Legumes	1.1
Onions	0.9
Corn	1.2
Potatoes	1.6
Pasture	1.9
Mint	1.6
Strawberries	1.5
Alfalfa	2.2
Asparagus	1.6

many years and not just 1979 conditions. Because no attempts were made to model the effects of soil conditions or microclimates on water requirements, the estimates may vary from actual 1979 crop-water consumption rates. However, the method does provide a generalized estimate of the demand placed on regional water supplies and a perspective on regional patterns of water consumption.

MODELING IRRIGATION ENERGY REQUIREMENTS

The estimation of 1979 irrigation energy requirements was completed using a COE formula (Whittlesey and Buteau, 1980) in a physical model. It was developed as a tool to estimate power requirements in the Columbia River Basin but was never used in a spatial context. By using the equation with spatial data, it was possible not only to estimate total energy requirements but also to produce a map which spatially portrays power requirement patterns. The formula that estimates kilowatt-hours per acre (kWh/acre) of energy consumption is

$$\text{kWh/acre} = \frac{(1.024) \times (\text{Diversion}) \times (\text{TDH})}{\text{Epp}}$$

where

1.024 = a constant that standardizes the equation;
Diversion = acre-feet of water diverted for irrigation;
TBD = Total dynamic head based on the sum of the pump lift, friction loss during delivery, and the system operating pressure; and
Epp = Pumping plant efficiency (which is estimated to be 85 percent in this area.)

The diversion requirements are based on the types of crops irrigated while TDH is primarily based on landscape position. The remainder of the equation uses nonspatial data and reduces to constant values for the study area.

Total Dynamic Head Analysis. The calculation of TDH required analyzing the relationship between the water's source and the point of use. In this study, it was assumed that all water would be diverted from the Columbia River using existing pumping plants.

DTT elevation data were used to determine the required pump lift. By subtracting the pool elevation of the Columbia River from the basinwide elevation file, the pump lift distance in feet for each acre in the study area was calculated. Friction loss was estimated by calculating the minimum distance between the nearest pumping plant and all points (data-base cells) throughout the basin. The distances were determined using the pumping plant location file and a radius calculation procedure. The distances, calculated in one-half-mile intervals, were multiplied by 11.12 to estimate friction loss. The friction loss and pump lift data were then added to the system operating pressure (240 feet of static lift was the assumed operating pressure) to produce the TDH file.

Diversion. The diversion data needed in the energy equation were based on the 1979 crop-water requirements file created earlier. The water requirements estimates for each of the 36 categories were increased by 22 percent (to allow for water lost during transmission) in order to create the diversion file.

1979 Irrigation Energy Requirements. With the spatial elements of the energy equation assembled, they could then be linked in the model with the nonspatial terms to estimate 1979 energy requirements. The modeling was completed using simple multiplication and division as specified by the energy formula. The result was a spatial classification of lands based on their 1979 energy requirements (Plate 3). In addition, the analysis estimated that 292 million kWh of energy were used for the 1979 irrigation season. The combined results not only provided an estimate of the impact irrigation placed on regional power supplies but also indicated patterns of energy use that may aid in identifying future consumption trends.

Potential Irrigation Energy Requirements. The use of a hypothetical diversion figure permitted the classification of lands in the Umatilla Basin according to their potential energy requirements. This was accomplished using a diversion of 2.81 acre-feet (this is the diversion figure suggested by Whittlesey and Buteau for use in regional power analysis). The resulting potential energy requirements file was included in the geographic data base for later use in determining the irrigation development potential of the Umatilla Basin (Plate 4).

MODELING IRRIGATION DEVELOPMENT POTENTIAL

The final analysis task of the project involved the use of a cartographic overlay model to predict

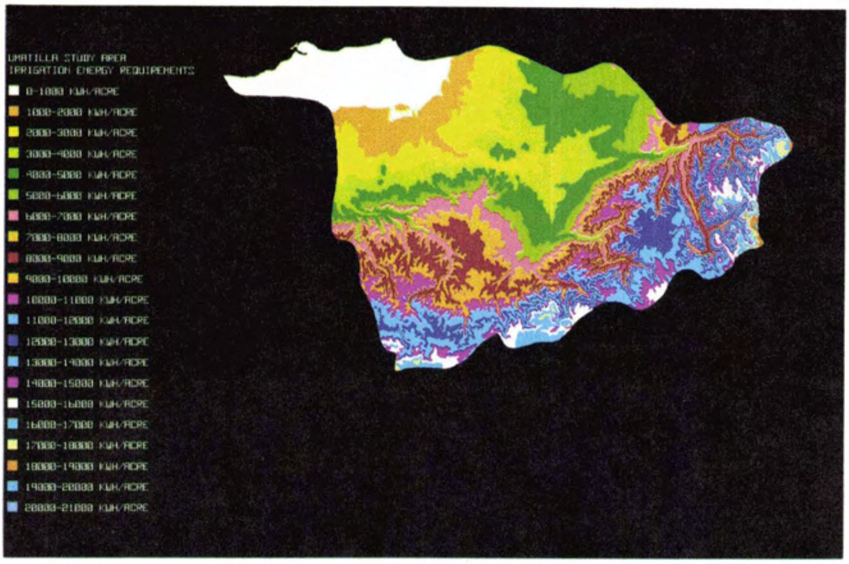

PLATE 4. Potential energy requirements for Umatilla Basin irrigation.

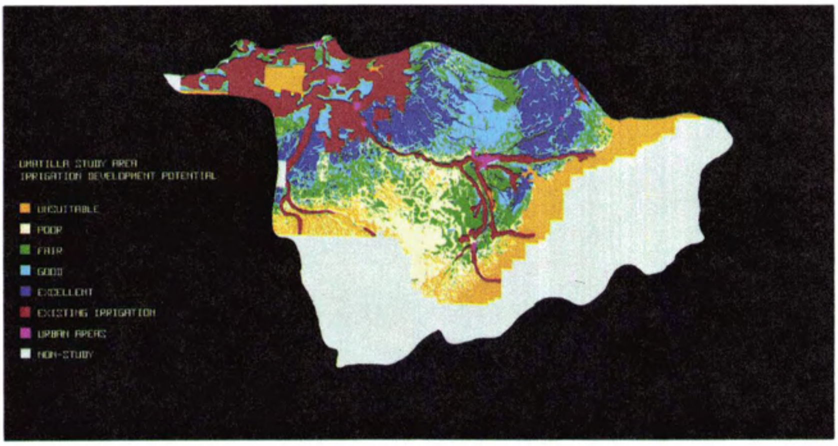

PLATE 5. Irrigation development potential composite map.

the irrigation development potential of the northern 1.1 million acres of the Umatilla Basin.* The model used data representing land cover, soil irrigability, percent slope, land-ownership, and potential energy requirements. Based on the characteristics of all the variables, the following assumptions were developed by EDC and COE scientists and used to determine variable weights for the overlay analysis. Table 6 contains the variable weighting scheme developed from these assumptions.

- Energy costs have twice as much impact on potential irrigability as any other factor.
- Physical factors of soils, slope, and land cover are of equal importance.
- Land-ownership is important only for eliminating a land parcel from consideration for irrigation development.
- While both dryland agricultural land and rangeland are considered irrigable, the dryland agricultural lands are more favorable for irrigation development.
- Water bodies, wetlands, urban areas, and forestlands cannot be irrigated.

* Soil survey data were only available for the northern 1.1 million acres of the 1.6-million-acre basin. For this reason, the irrigation potential modeling was restricted to the lands where complete soil survey existed. Most of the excluded lands are in National Forests.

TABLE 6. WEIGHTING SCHEME DEVELOPED FOR COMPOSITE MAPPING. POTENTIAL ENERGY REQUIREMENTS (NOT SHOWN IN THIS TABLE) USED A 20 TO 1 NUMERIC RANGE WITH 20 REPRESENTING THE LOWEST COSTS (400 kWh/ACRE) AND 1 FOR HIGHEST COSTS (10,500 kWh/ACRE).

Numeric Value (Weight)	Model Inputs			
	Land Cover	Land Ownership	Soils	Slope (Percent)
10	Dryland agriculture	Private ownership	Excellent	0–3
9	—	—	—	—
8	—	—	—	—
7	Rangeland	—	—	4–7
6	—	—	Good	—
5				
4	—	—	—	8–12
3	—	—	Fair	—
2	—	—	—	—
1	—	—	Poor	—
not considered for irrigation suitability	Existing irrig. Water bodies Urban areas Wetlands	Wildlife area Military reservation State parks National forests	Unsurveyed	13+

- Lands with slopes from 0 to 3 percent are most favorable for irrigation, those with slopes from 4 to 7 percent are less favorable, and those with slopes from 8 to 12 percent are least favorable.
- Lands with slopes of 13 percent or greater are non-irrigable.
- All soils are irrigable although they range from excellent to poor.

An additive overlay process was used for the actual modeling. The scores assigned to tbe variables were summed cell by cell to produce a composite score of irrigation potential. At the same time, the presence of variable categories that rendered the area nonirrigable (wetlands, steep slopes, wildlife refuges, etc.) was tested in order to eliminate areas that have adverse conditions. The cumulative scores for the potentially irrigable land were evaluated and threshold scores were determined by EDC and COE scientists (Table 7). Using the thresholds, the raw scores were assigned to irrigation development potential categories and the final map was produced (Plate 5).

The irrigation development potential map illustrates the region's development potential based on a specific set of assumptions. As conditions change, the results would change. However, because of the flexibility afforded by the digital data base, it is possible to efficiently repeat the analysis procedure using new decision criteria. The modeling effort using physical variables (soils, slope, and land cover), administrative factors (landownership), and economic considerations (energy requirements) provided a unique opportunity to anticipate the impact of potential Umatilla Basin irrigation development in future years.

TABLE 7. CATEGORIES, SCORES, AND FREQUENCY OF THE IRRIGATION DEVELOPMENT POTENTIAL COMPOSITE MAP.

Category	Composite Scores	Occurence (Percent)
Unsuitable	0–31	20
Poor	32–44	21
Fair	45–50	21
Good	51–53	19
Excellent	54–58	19

DISCUSSION

Remotely sensed data, used independently and with other spatial data, provided descriptive statistics and maps needed to understand irrigation characteristics in the Umatilla Basin. Basic land-cover and crop-type inventory data provided the COE with information describing the number of acres irrigated in 1979, the types of crops and their acreages irrigated in 1979, and the rate of center-pivot irrigation growth based on 1973–79 trends. The detailed digital crop classification results were combined with supporting data to estimate the impact of 1979 irrigation on regional water and power supplies. A simple translation from crop-type to water requirements provided an estimate of the acre-feet of water used for irrigation. A more complex physical model using pumping plant location and digital elevation data with Landsat-derived crop-water requirements produced an estimate of 1979 irrigation energy requirements. Finally, a land-cover interpretation and data describing soil irrigability, percent slope, landownership, and potential energy requirements were used in a cartographic model to determine the irrigation development potential for much of the Umatilla Basin.

Remotely sensed data were used in the study in several ways. Landsat data provided an efficient base from which area-wide inventories could be completed. The retrospective and repetitive nature of the data not only permitted a look at the basin in previous years so that trends could be detected, but also will allow updating baseline information. In coming years, new impacts can be measured, and development trends can be monitored. Landsat FCC's provided a comprehensive assessment of land-cover patterns without the need for complex analysis tools and techniques. In addition, the spatial generalization to the 40-acre minimum mapping unit was adequate for regional characterization of development suitability. Digital Landsat data were useful because the high resolution (1.1 acre) permitted the analysis of complex classes of information with the spatial resolution needed to produce more precise estimates. The digital data provided an effective sampling frame from which refined estimates could be made in order to mitigate misclassification.

Spatial data in a variety of forms were readily used with the remotely sensed data. No problems were identified that prevented the accomplishments of a project goal. The terrain data were relatively easy to reformat for the data base because they existed in a gridded UTM format. The remaining map-based data, such as soil, land-ownership, and pumping plant locations, required digitizing which increased analysis time and costs. Fortunately, these variables seldom change and thus will not need to be redigitized for future investigations. The spatial and remotely sensed data provided a unique look at past, present, and future characteristics of irrigation development in the Umatilla Basin. Increased benefits, at reduced costs, will be realized in the future, when modeling of irrigation potential is repeated using new scenarios or when new estimates of resource consumption are needed.

Acknowledgment

The work described in this paper was performed under U.S. Geological Survey Contract No. 14-08-0001-16439.

References

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer, 1976. *A land use and land cover classification system for use with remote sensor data:* U.S. Geological Survey Professional Paper 964, 28 p.

Fleming, M. D., S. S. Berkebile, and R. M. Hofer, 1975. *Computer aided analysis of LANDSAT-1 MSS data: a comparison of three approaches including a "modified clustering" approach:* Purdue University, Laboratory for Applications of Remote Sensing, LARS Information Note 072475, 9 p.

Rohde, W. G., and W. A. Miller, 1981. *Arizona vegetation resource inventory,* final report: U.S. Geological Survey EROS Data Center, Sioux Falls, So. Dak., 79 p.

Soil Survey Staff, 1948. *Soil survey—the Umatilla area, Oregon:* U.S. Department of Agriculture Series 1937-No. 21, Washington, D.C., 125 p.

Swan, G. A., T. G. Withrow, and D. L. Park, 1980. *Survey of fish protective facilities at water withdrawals on the Snake and Columbia River:* Seattle, Wash., Coastal Zone and Estuarine Studies Division, National Oceanic and Atmospheric Administration, 189 p.

U.S. Army Corps of Engineers, Portland District, 1979. *Columbia Basin water withdrawal environmental review;* Appendix A—Land Use: Portland, Ore., 26 p.

U.S. Geological Survey, 1980. *National Cartographic Information Center digital terrain tapes—a users guide:* U.S. Government Printing Office: 1980 0-311-344/184, 12 p.

U.S. Soil Conservation Service, 1973. *Oregon irrigation guide:* Portland, Ore., 91 p.

Whittlesey, N. K., and J. R. Buteau, 1980. *Pumping energy for irrigation development in the Pacific Northwest, Portland, Ore.:* U.S. Army Corps of Engineers, 13 p.

(Received 23 March 1982; accepted 4 November 1982; revised 3 March 1983)