Remote sensing applied to the cadastre of irrigation water users in a GIS environment

Sensoriamento remoto aplicado ao cadastro de irrigantes e seu uso em ambiente GIS

Christopher M. U. Neale

Professor
Dept. of Civil and Environmental Engineering
Irrigation Engineering Division
Utah State University

Why do we need a cadastre of irrigators?

Porque precisamos de um cadastro de irrigantes?

- In many countries, water is still distributed in fixed amounts and charged according to area served and not on volume. Therefore a good estimate of area of each irrigated property is needed for proper assessment of system operation and maintenance fees.
- An up-to-date cadastre of irrigators is necessary in the transfer of publicly operated system to private irrigator cooperatives
- A cadastre can lead to improved water management

Outline of the Presentation

- Describe the development of a digital cadastre of irrigation water users in the Dominican Republic
- Show how it was used in the transfer or irrigation systems to the private sector
- Elaborate on how the information can be used in modeling of irrigation systems and improving water management

Estudios Básicos Para El Manejo de Los Sistemas de Riego

Programa de Administración de Sistemas de Riego por los Usuarios (PROMASIR)
Préstamo BID 905/OC-DR

Instituto Nacional de Recursos Hidráulicos
INDRHI

Dominican Republic

Basic Studies for Management of Irrigation Systems

- Contract between INDRHI and (Utah State University) funded by the Inter-American Development Bank
- $7.9 million dollars
- Duration: 4 ½ years
- Comprised 4 studies:

1. Aerial Photography of the Entire Country
2. Cadastre of Water Users (Padrón de Usuarios)
3. Hydro-Agricultural Information System
4. Monitoring of Salinity and Drainage Problems

These studies had the objective of providing basic information required for the transfer of Operation and Maintenance of 30 canal-based irrigation systems from the government control (INDRHI) to newly formed Irrigation Water User Associations

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Remote Sensing based Products

- Color aerial photographs at 1:20,000 scale of the entire country in digital format
- Color contact prints of the aerial photography at 1:20,000
- Color and Black and White diapositives at 1:20,000
- Digital orthophotoquads at 1:5000 for the irrigated areas of the country: (4400 Km2)
- Contour curves at 1-meter intervals, of the irrigated areas (ortofotos)
- High resolution multispectral image mosaics of the irrigated areas
- Digital Cadastre of Irrigation Water Users and Information Database for all the irrigation systems of the country

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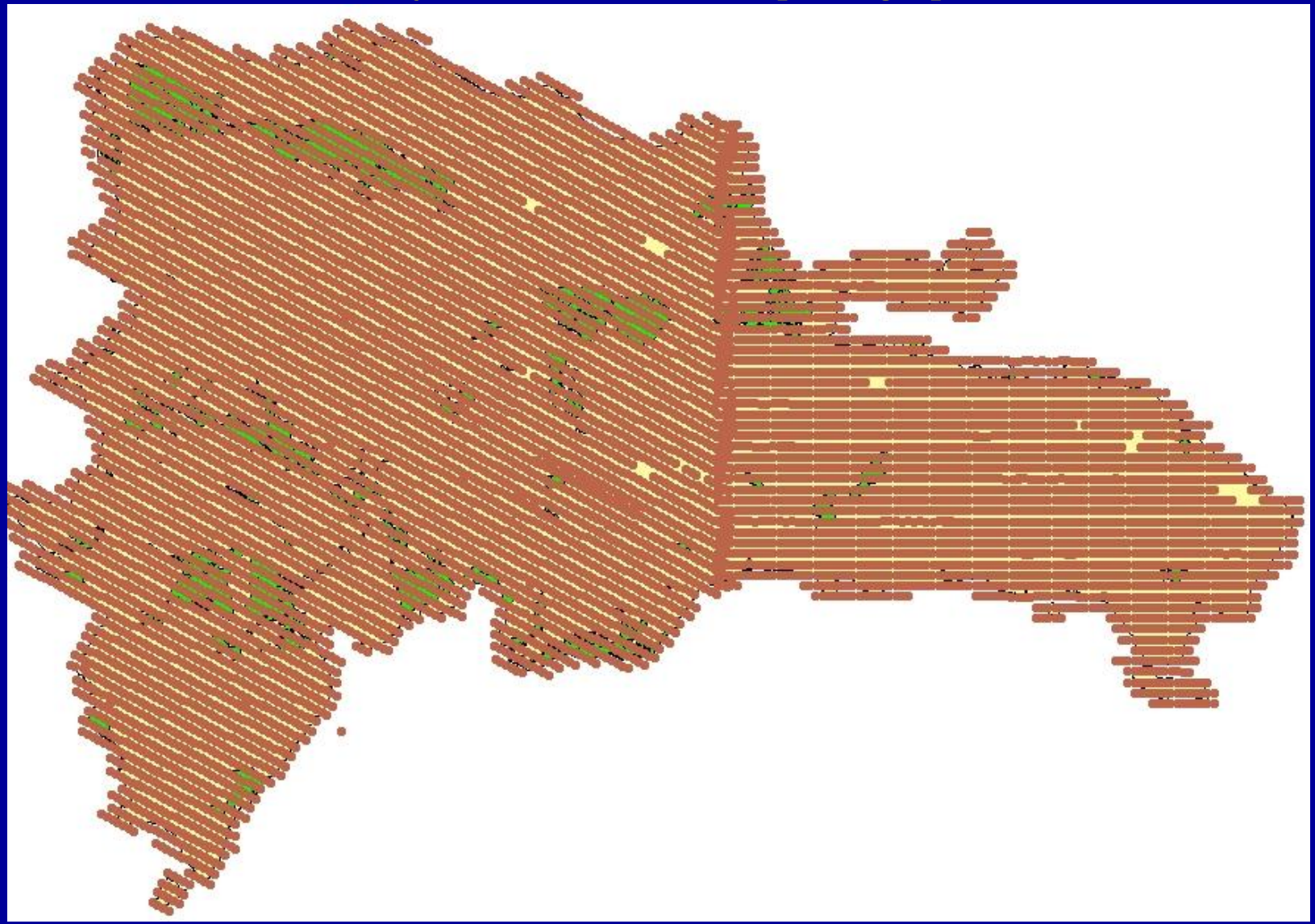
Final Results of the Aerial Photography Campaign

99.6 % of the Country covered with color photographs at 1:20000 scale



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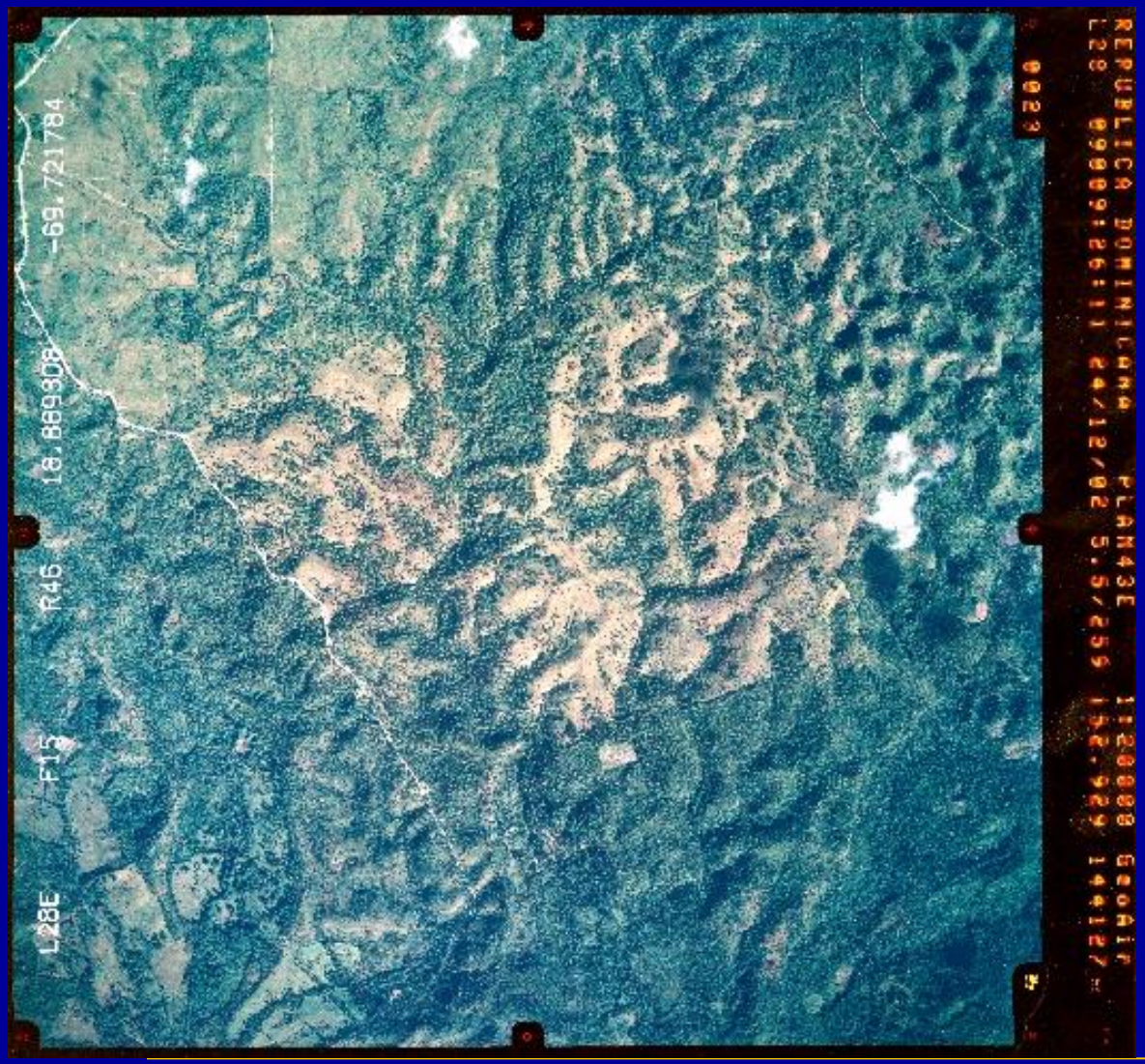
Digital Aerial Photograph at 1:20,000 scale

The Basic Product



Resulting from the scanning of the negative with software producing a color digital positive

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Contact Prints at 1:20,000

Printed on photographic quality paper

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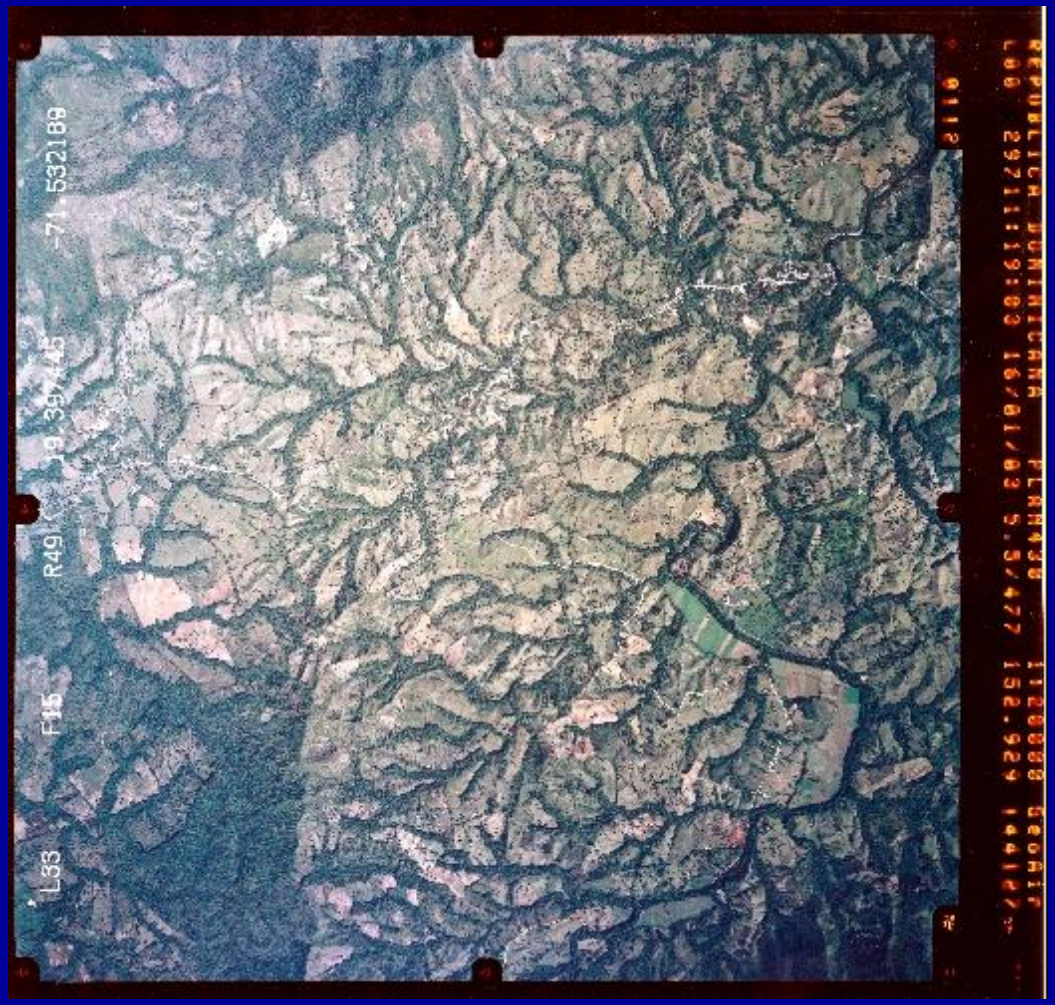
Diapositive of the original photo:

Used in analytical stereoplotters for the production of orthophotos and updating of topographic maps



Diapositives are transparent photos (like a slide)

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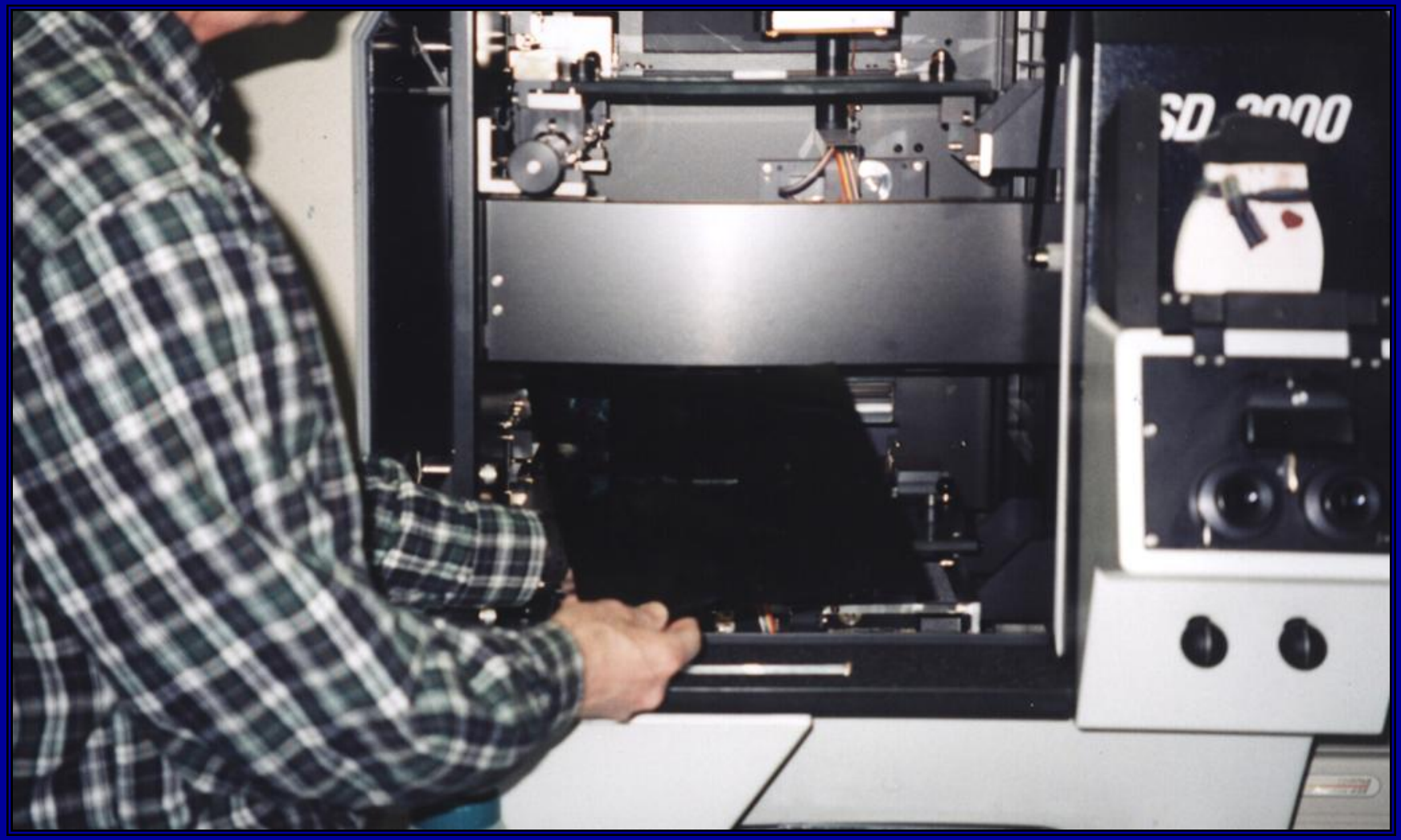
Diapositives are used in Analytical Stereo Plotters like the *Leica SD2000 for example*



Surveying of Ground Control Points used in the aerial triangulation and production of orthophotos

High Precision Dual frequency GPS systems were used to obtain the ground control points for mapping

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Installation of GPS base station network

to support aerial photography and ground control activities

Data from the base stations were used to correct the positions of the mobile units based on differential correction techniques, resulting in high positional accuracy. The network of GPS base stations installed was similar to the CORS network in the US.

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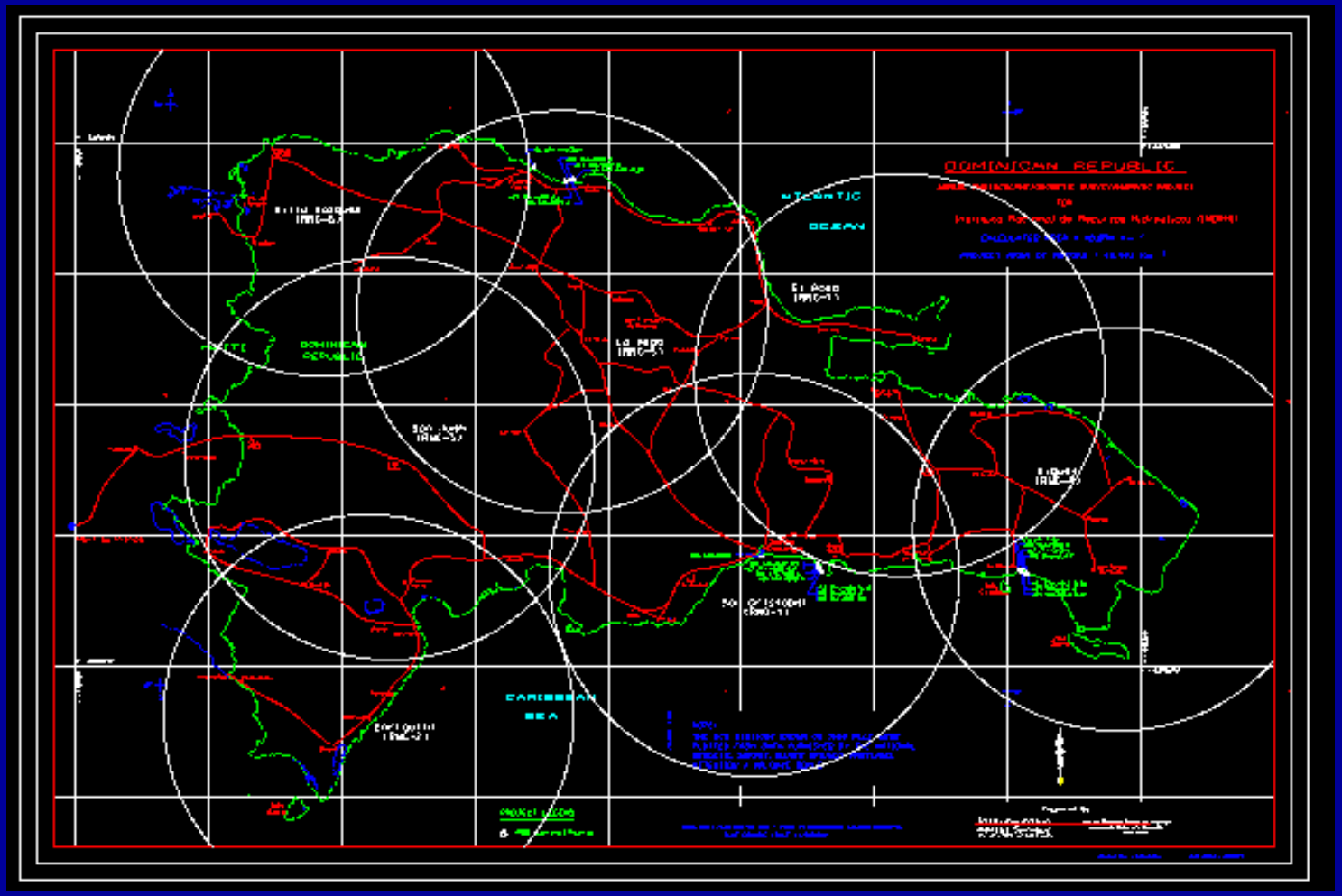
Location of the GPS Base Station in the DR

San Cristóbal, Barahona, San Juan, Villa Vázquez, La Vega, Nagua, Higuey



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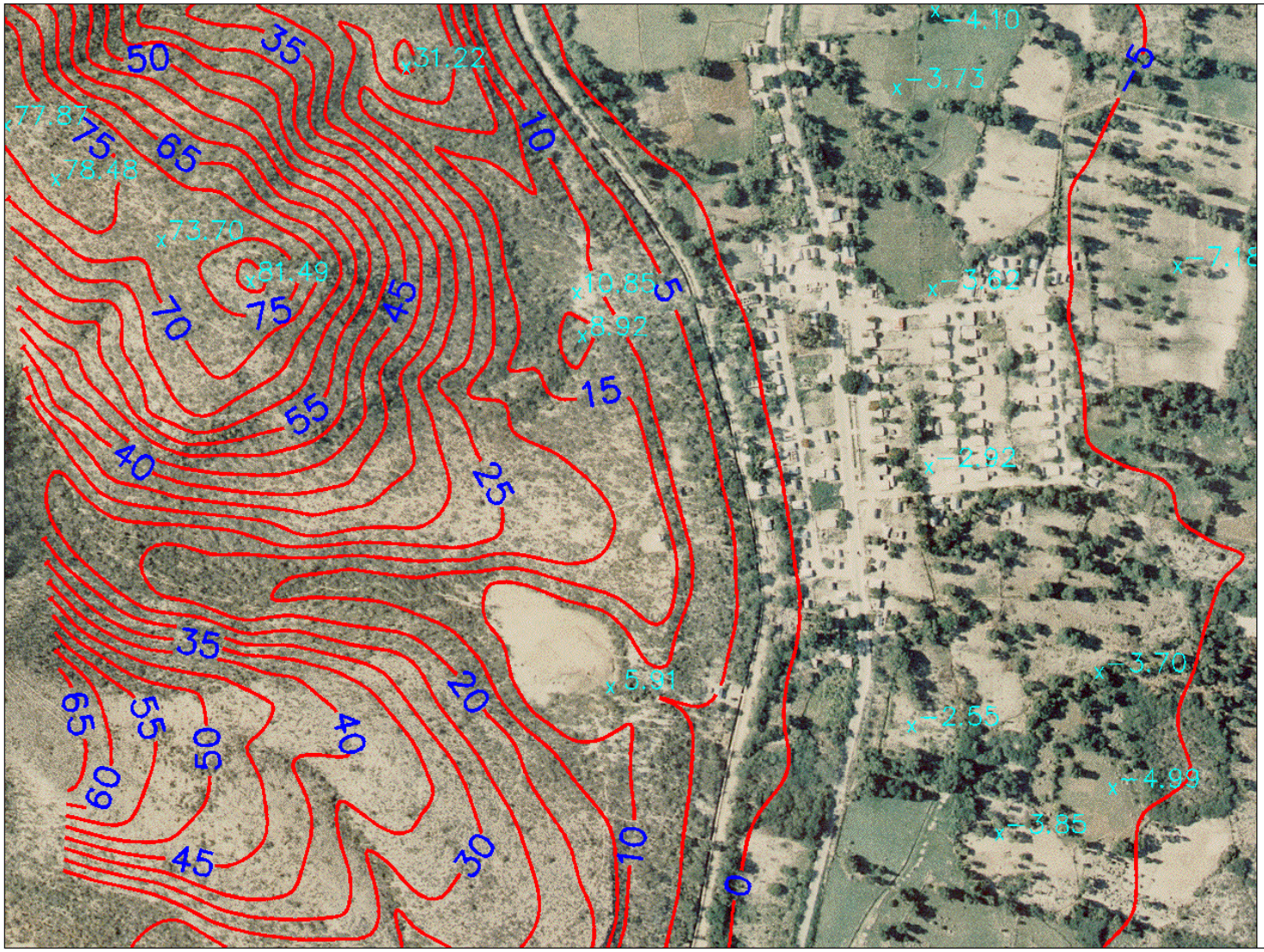
Digital Orthophoto with Contour Lines of the irrigated areas República Dominicana



Project Design before this Project:

Traditional design drawing and cartography

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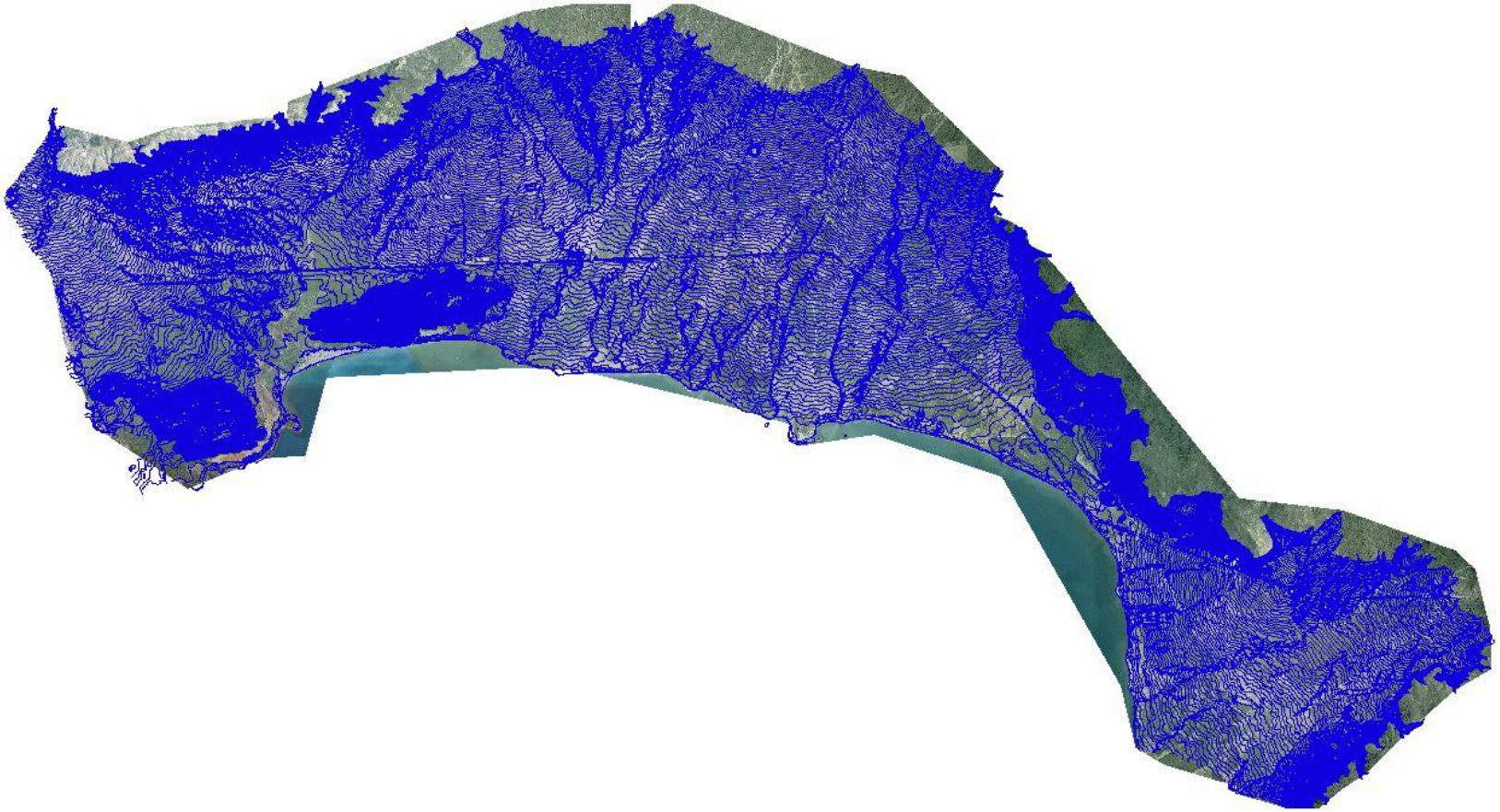
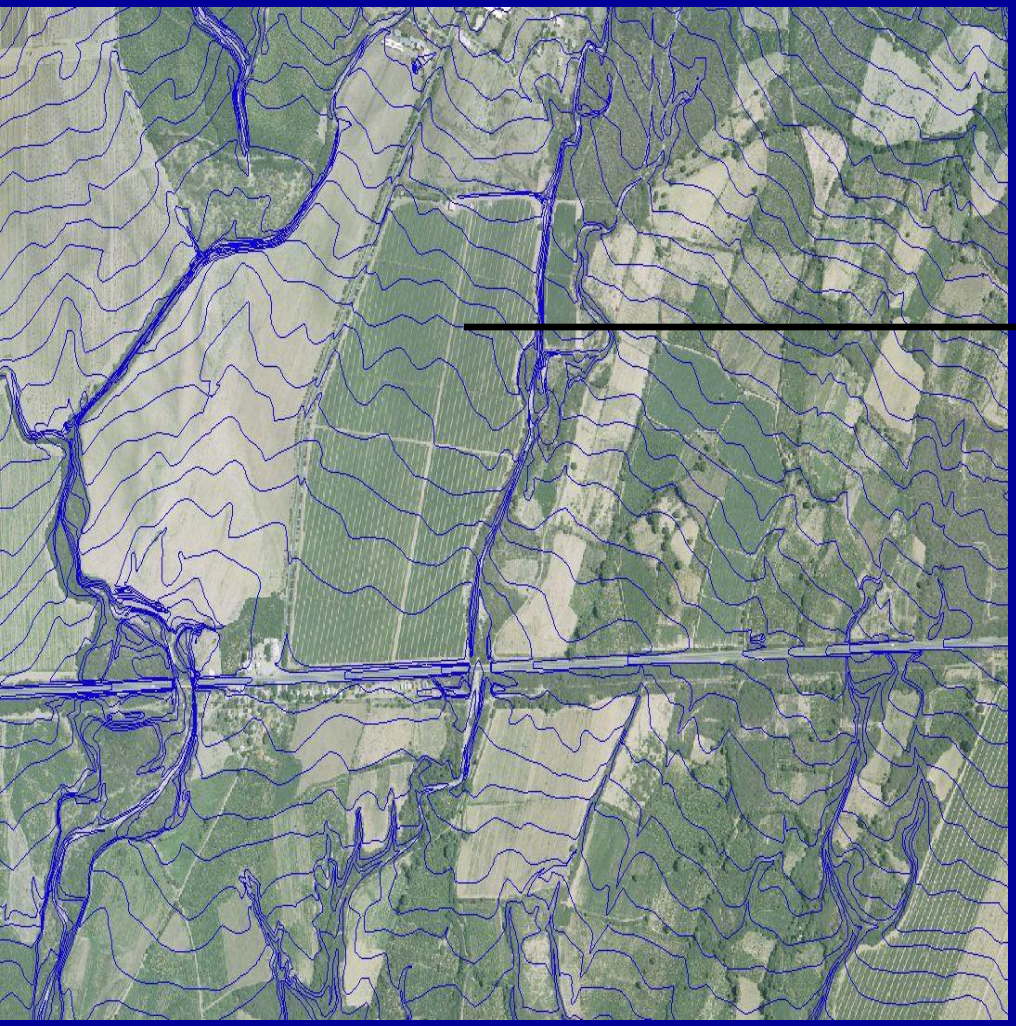
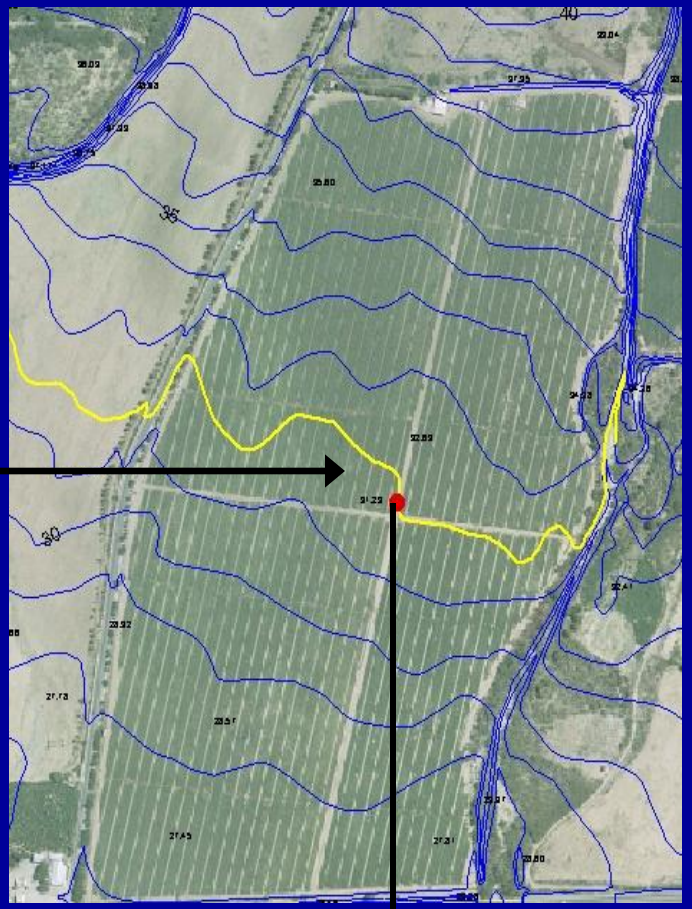
After the development of the digital products, planning for irrigation of new systems was done digitally, such as the Azua II Irrigation Project

Digital Orthophoto Mosaic with Contour Curves at 1-meter intervals



Detail of a Digital Orthophoto with Contours





COORDENADAS

X	326029
Y	2040262
Z	32

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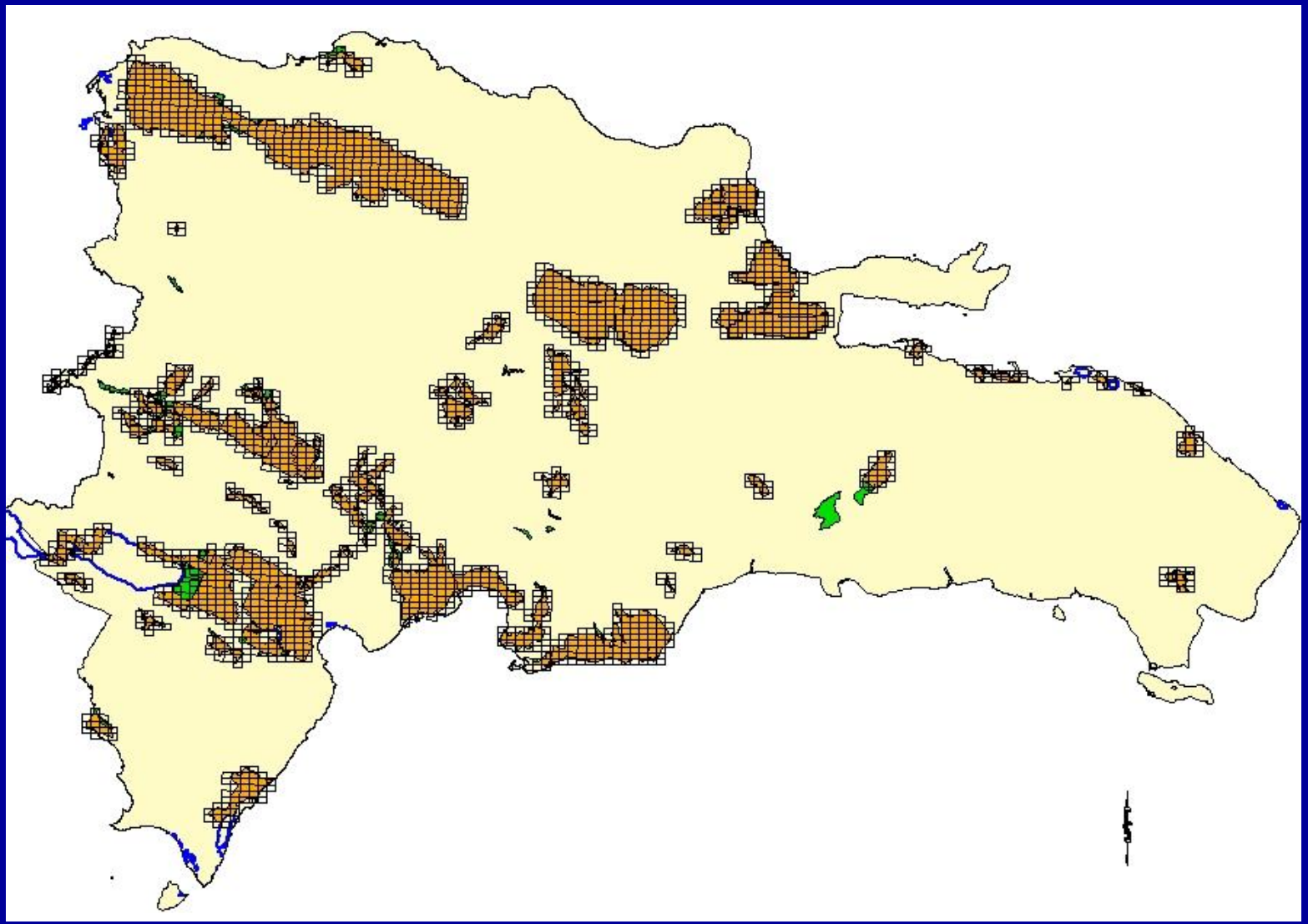
Digital Orthophotos

covering 4430 Km2 of irrigated areas in the country



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Airborne Multispectral Mosaics of the Irrigated Areas

- Acquired with the USU digital airborne multispectral system
- Used in the study of salinity and drainage problems of the irrigation areas of the country
- Used to obtain the crop cover and land use for the hydro-agricultural database system
- Maps of areas with salinity impacts and drainage problems

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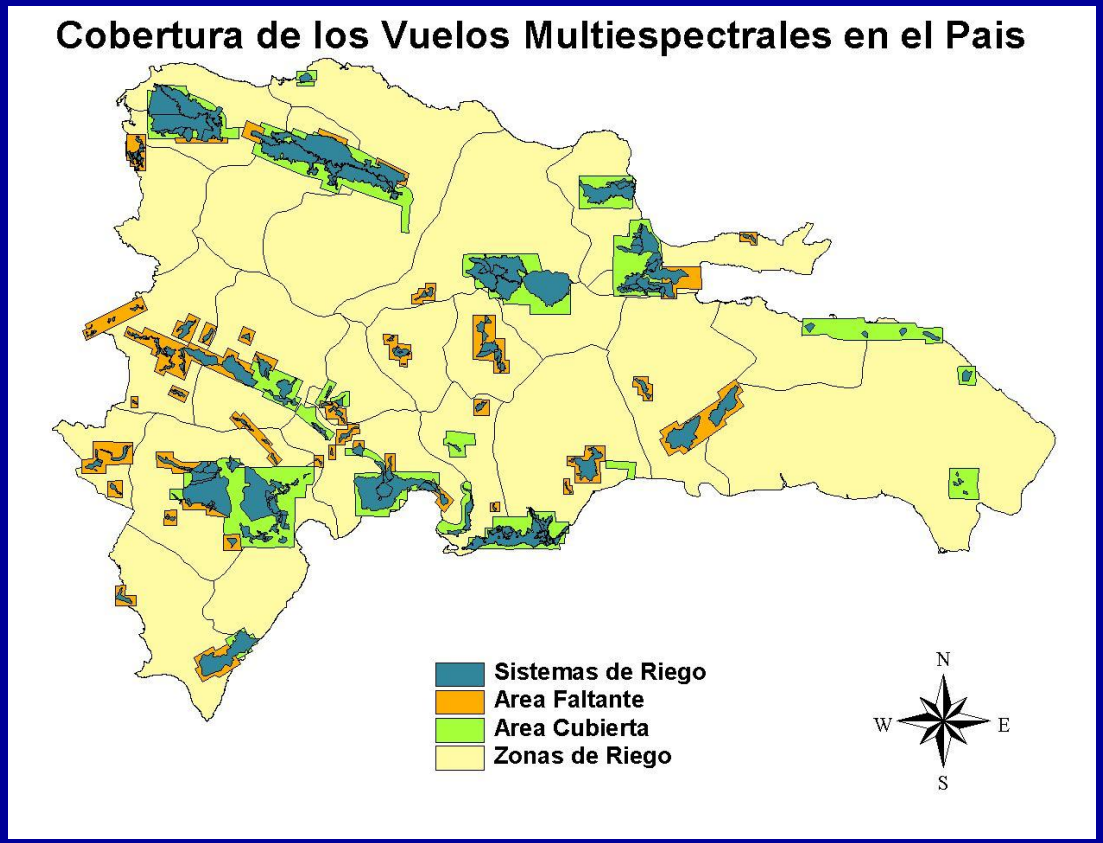
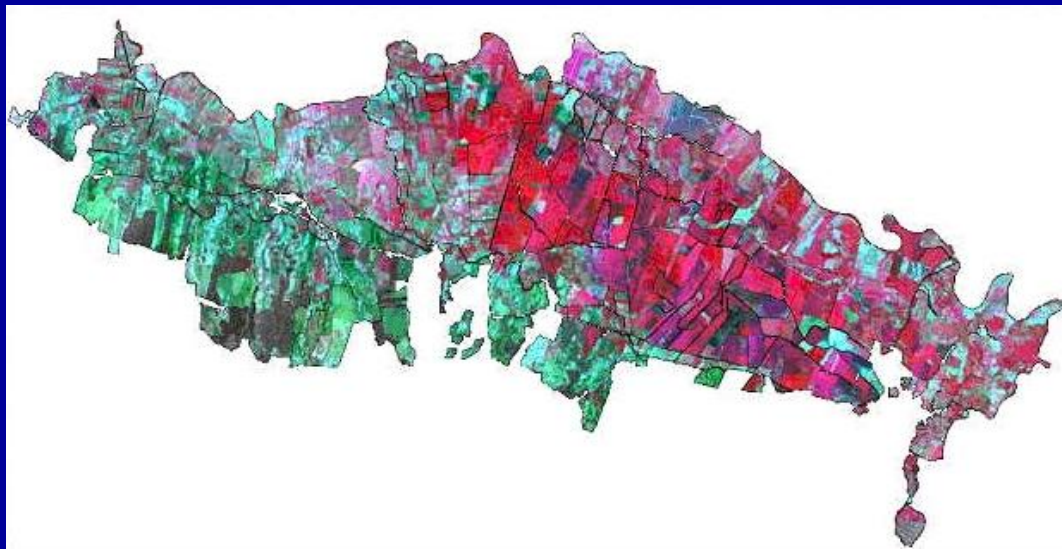
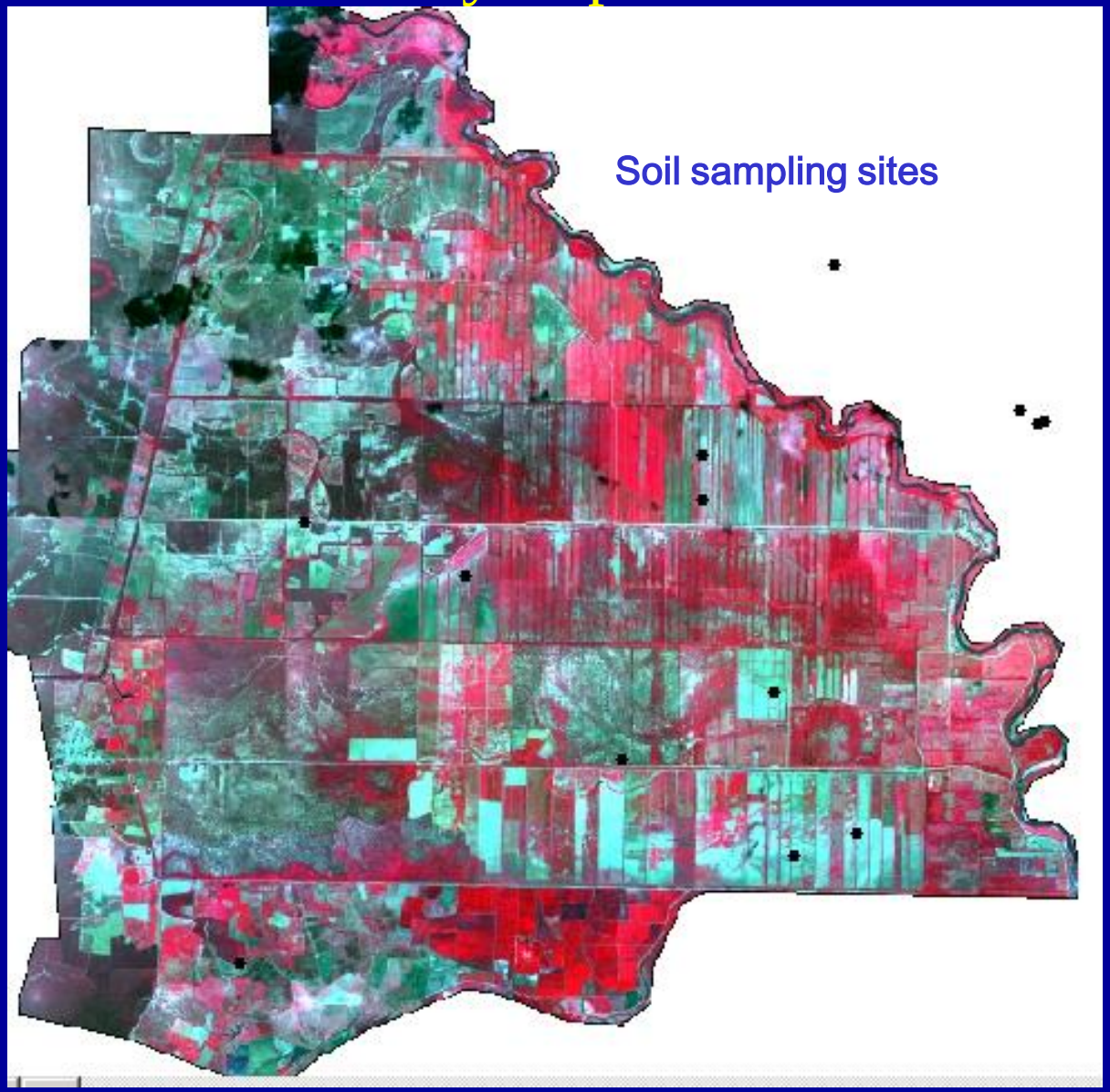


Multispectral Mosaic of The Mao-Gurabo Irrigation System



Multispectral Mosaic of the Manzanillo Area used for Salinity Impact studies



Results were verified with intensive soil sampling

What is a Digital Cadastre of Irrigators?

It is a database containing information on all the property owners and irrigation water users within an irrigation project or system. It consists of:

- An up-to-date property boundary map containing information on every property owner or water user
- Information on total area and irrigated area of each property
- Information on the canal system that delivers water to the property

=> Because of the geographic and distributed nature of the information as well as the requirement to have an associated database, USU opted in using Geographic Information System (GIS) technology to develop this product.

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Digital Orthophoto at 1:5000 scale

The map base for the cadastre of irrigation water users

The orthophoto is a digital photograph with geographic coordinates that has been adjusted to the terrain so that areas can be correctly measured

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Printed Orthophoto at 1:4000 scale were used for field verification of property boundaries

Field brigades used printed and laminated maps to identify the property boundaries together with the land owner or a local facilitator that has a good knowledge of the irrigation system (president of a water association, ditch rider)

A brigade consisted of 4 to 6 trained cartographers with one 4x4 dual cabin pickup and 3 or 4 cross-country motorbikes

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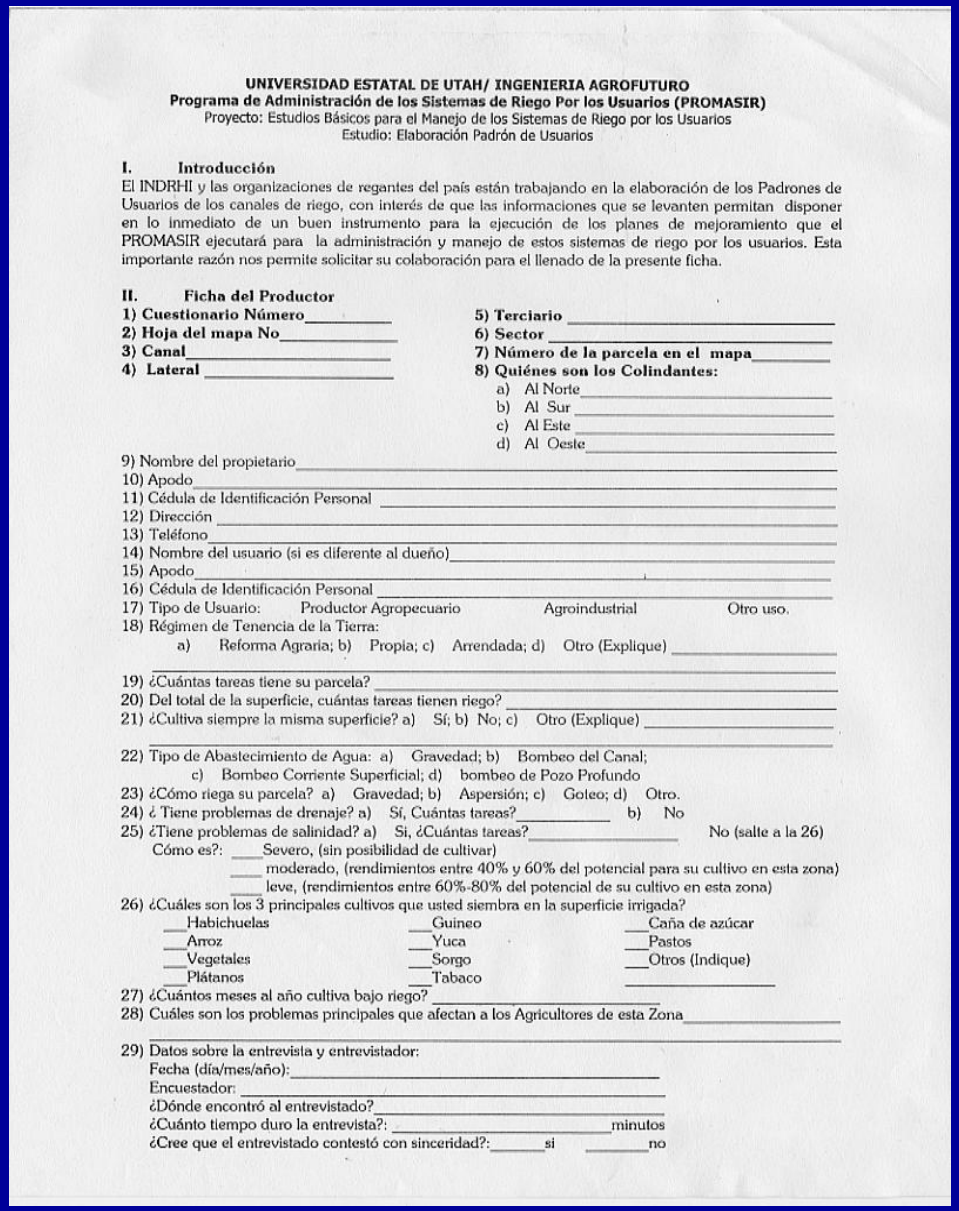
Survey Form used in Information Gathering by the Cartographers



UNIVERSIDAD ESTATAL DE UTAH/ INGENIERIA AGROFUTURO
Programa de Administración de los Sistemas de Riego Por los Usuarios (PROMASIR)
Proyecto: Estudios Básicos para el Manejo de los Sistemas de Riego por los Usuarios
Estudio: Elaboración Padrón de Usuarios

I. Introducción

El INDRHI y las organizaciones de regantes del país están trabajando en la elaboración de los Padrones de Usuarios de los canales de riego, con interés de que las informaciones que se levanten permitan disponer en lo inmediato de un buen instrumento para la ejecución de los planes de mejoramiento que el PROMASIR ejecutará para la administración y manejo de estos sistemas de riego por los usuarios. Esta importante razón nos permite solicitar su colaboración para el llenado de la presente ficha.

II. Ficha del Productor

1) Cuestionario Número_____
2) Hoja del mapa No_____
3) Canal_____
4) Lateral _____
5) Terciario _____
6) Sector _____
7) Número de la parcela en el mapa_____
8) Quiénes son los Colindantes:
a) Al Norte_____
b) Al Sur _____
c) Al Este _____
d) Al Oeste_____

9) Nombre del propietario_____
10) Apodo_____
11) Cédula de Identificación Personal _____
12) Dirección _____
13) Teléfono_____
14) Nombre del usuario (si es diferente al dueño)_____
15) Apodo_____
16) Cédula de Identificación Personal _____
17) Tipo de Usuario: Productor Agropecuario Agroindustrial Otro uso.
18) Régimen de Tenencia de la Tierra:
a) Reforma Agraria; b) Propia; c) Arrendada; d) Otro (Explique) _____
_____
19) ¿Cuántas tareas tiene su parcela? _____
20) Del total de la superficie, cuántas tareas tienen riego? _____
21) ¿Cultiva siempre la misma superficie? a) Sí; b) No; c) Otro (Explique) _____
_____
22) Tipo de Abastecimiento de Agua: a) Gravedad; b) Bombeo del Canal;
c) Bombeo Corriente Superficial; d) bombeo de Pozo Profundo
23) ¿Cómo riega su parcela? a) Gravedad; b) Aspersión; c) Goteo; d) Otro.
24) ¿ Tiene problemas de drenaje? a) Sí, Cuántas tareas?_____ b) No
25) ¿Tiene problemas de salinidad? a) Si, ¿Cuántas tareas?_____ No (salte a la 26)
Cómo es?: ___Severo, (sin posibilidad de cultivar)
____ moderado, (rendimientos entre 40% y 60% del potencial para su cultivo en esta zona)
____ leve, (rendimientos entre 60%-80% del potencial de su cultivo en esta zona)
26) ¿Cuáles son los 3 principales cultivos que usted siembra en la superficie irrigada?

___Habichuelas	___Guineo	___Caña de azúcar
___Arroz	___Yuca	___Pastos
___Vegetales	___Sorgo	___Otros (Indique)
___Plátanos	___Tabaco	_____

27) ¿Cuántos meses al año cultiva bajo riego? _____
28) Cuáles son los problemas principales que afectan a los Agricultores de esta Zona_____
_____
29) Datos sobre la entrevista y entrevistador:
Fecha (día/mes/año):_____
Encuestador: _____
¿Dónde encontró al entrevistado?_____
¿Cuánto tiempo duro la entrevista?: _____minutos
¿Cree que el entrevistado contestó con sinceridad?:_____si _____no

The cartographers conduct the survey with the property owner to obtain basic information on the water user (complete name, nickname, address) and on the property (delivery canal, water distribution problems, crops planted, salinity or drainage problems)

Information was digitized using an Access DB application to automate the data entry. This work was done in the Dominican Republic at a Lab in USU's local office.

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On-screen digitizing of the parcel boundaries in ArcInfo using the digital ortho as a backdrop

Most of the digitizing was done at USU using battalions of graduate and undergraduate student technicians. Also the merging with survey database and Quality Control

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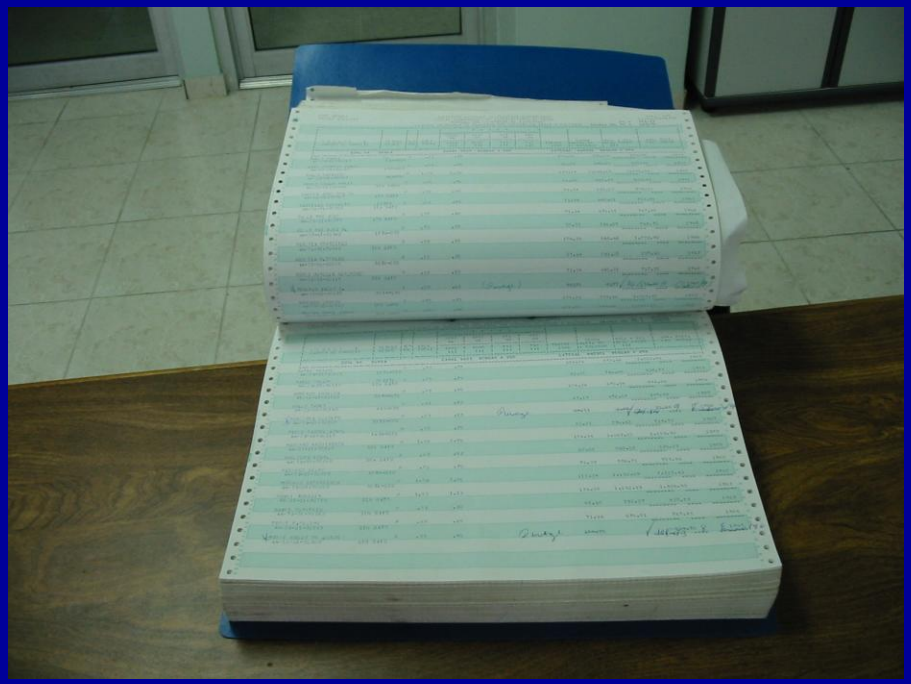
Observation: We were very good clients of FEDEX!

Some characteristics of the digital cadastre of irrigation water users

- Union of the geographic layer containing the property boundaries with the information in the surveys
- The geographic coordinates come from the digital orthophotos
- The property area is exact
- The database is complete because all properties within the command area of a main canal or irrigation system are included
- Can be readily and easily updated
- The property boundaries can be updated if a consolidation or division of properties occurs

The Water Users Database Prior to the Estudios Basicos Project

Essentially a listing of users => Rapidly became obsolete, areas were not correct, water users were repeated, owners of multiple properties sometimes were not registered and did not pay for the water. Some irrigation systems had property boundary maps but were static in time.



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The Hydro-Agricultural Information System was created to allow easy access to the Cadastre of Water Users Database and to Manage the Information

Software developed in MapObjects and Visual Basic

- Allowed the search of irrigators by first and last name, nickname etc.
- Visualize the irrigation control structures for maintenance purposes
- GIS Layers: Cadastre (property boundary), canal and drain system, hydraulic control structures, crop and land use layer, soil layers
- Allowed for the updating of the crop agricultural statistics
- Estimates the irrigation water demand through ET calculations on a canal command area level and also by lateral and entire project
- Product installed at the Water Users Associations and Irrigation Districts

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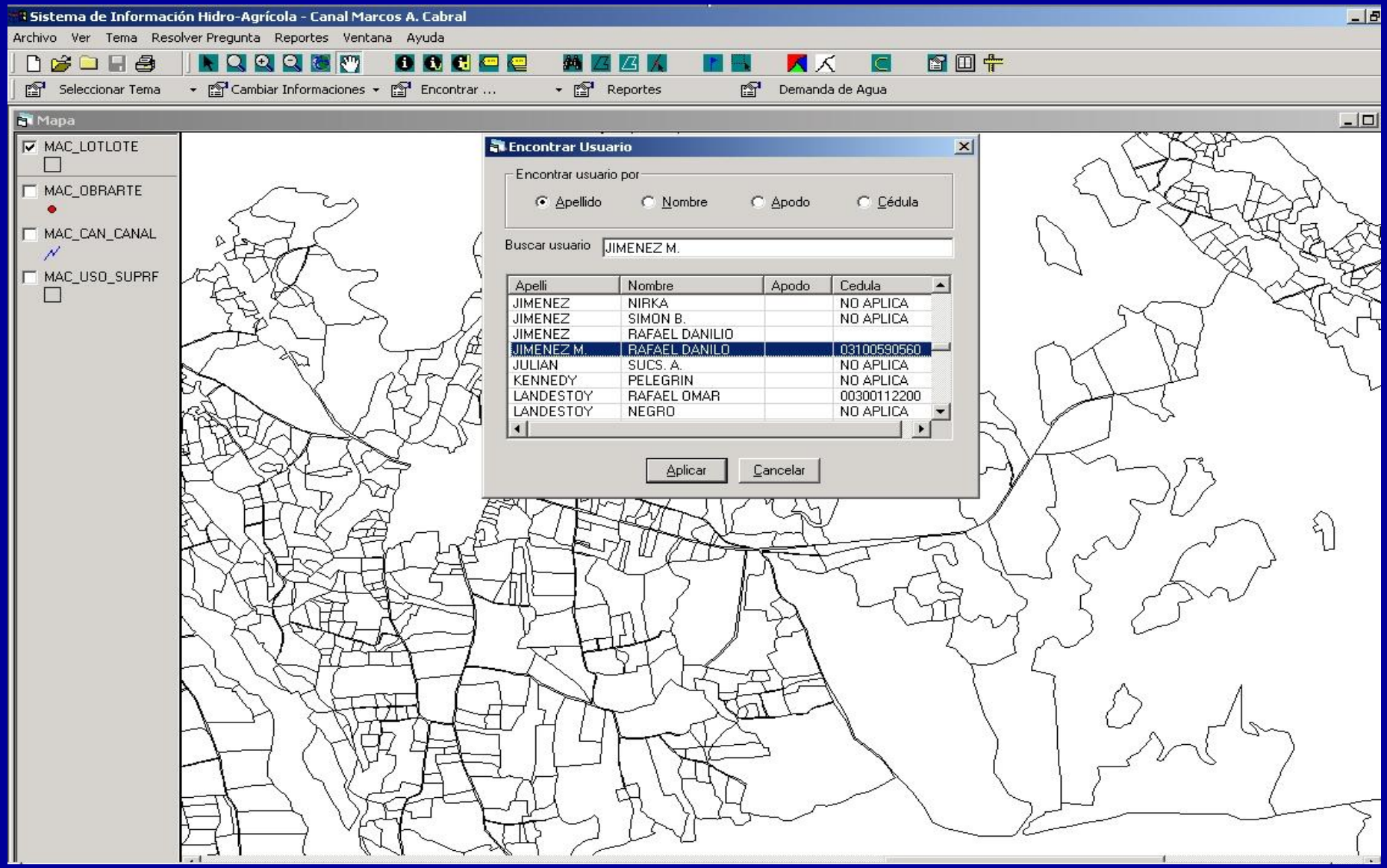
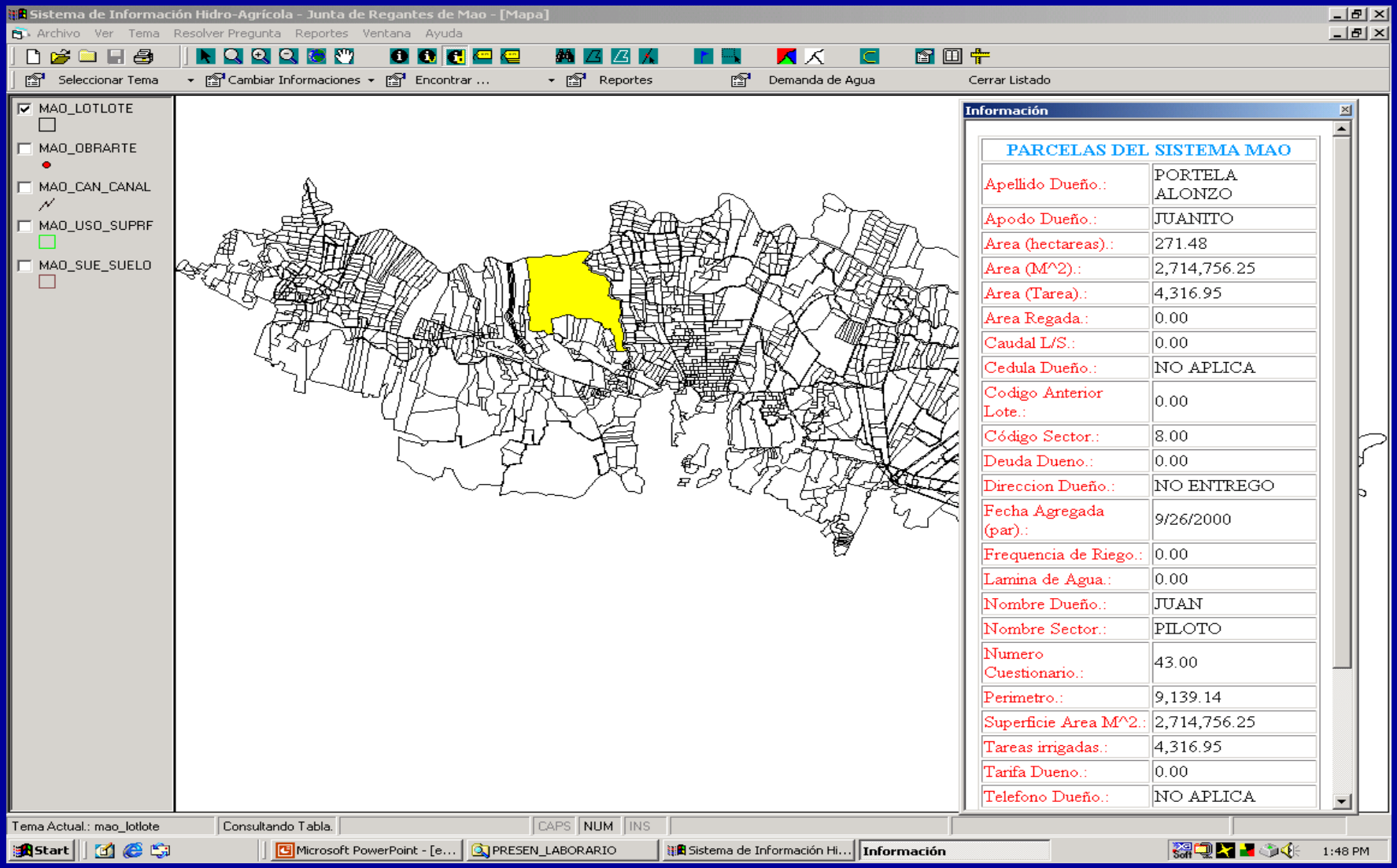
Example: Search for a Water User or Irrigator



Digital Database



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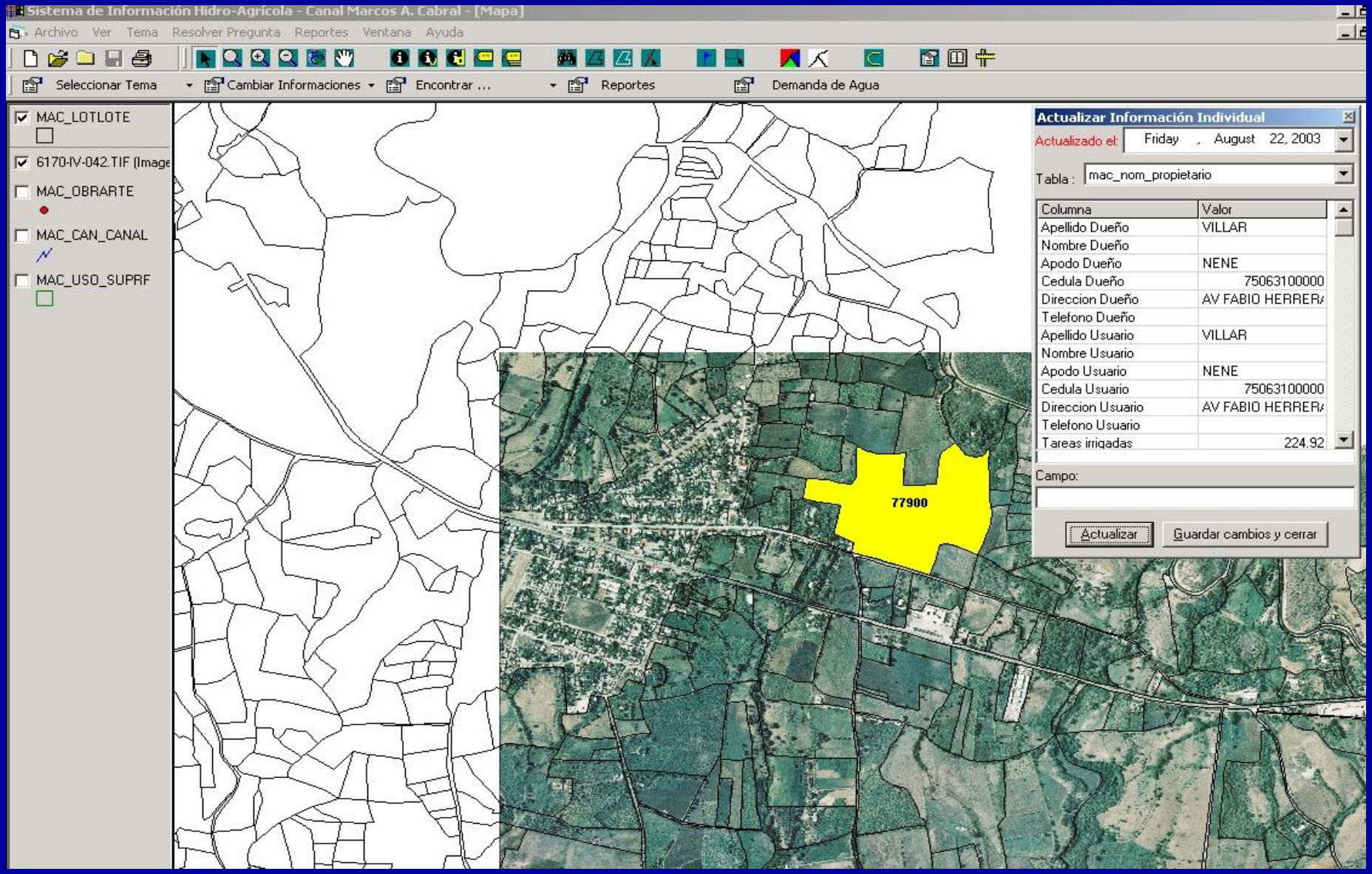
Information can be easily updated



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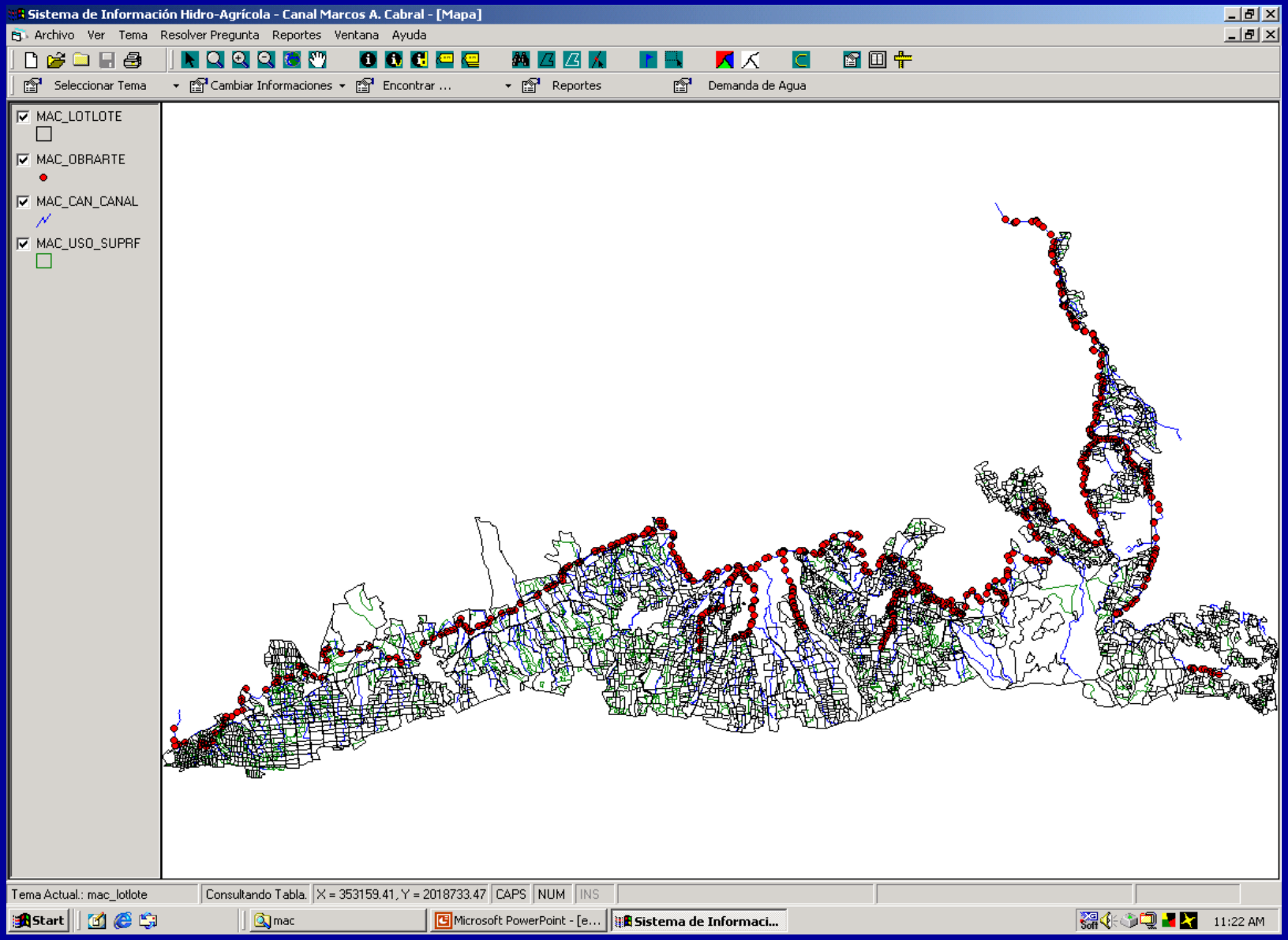
Information on irrigation infrastructure for Marcos A. Cabral System



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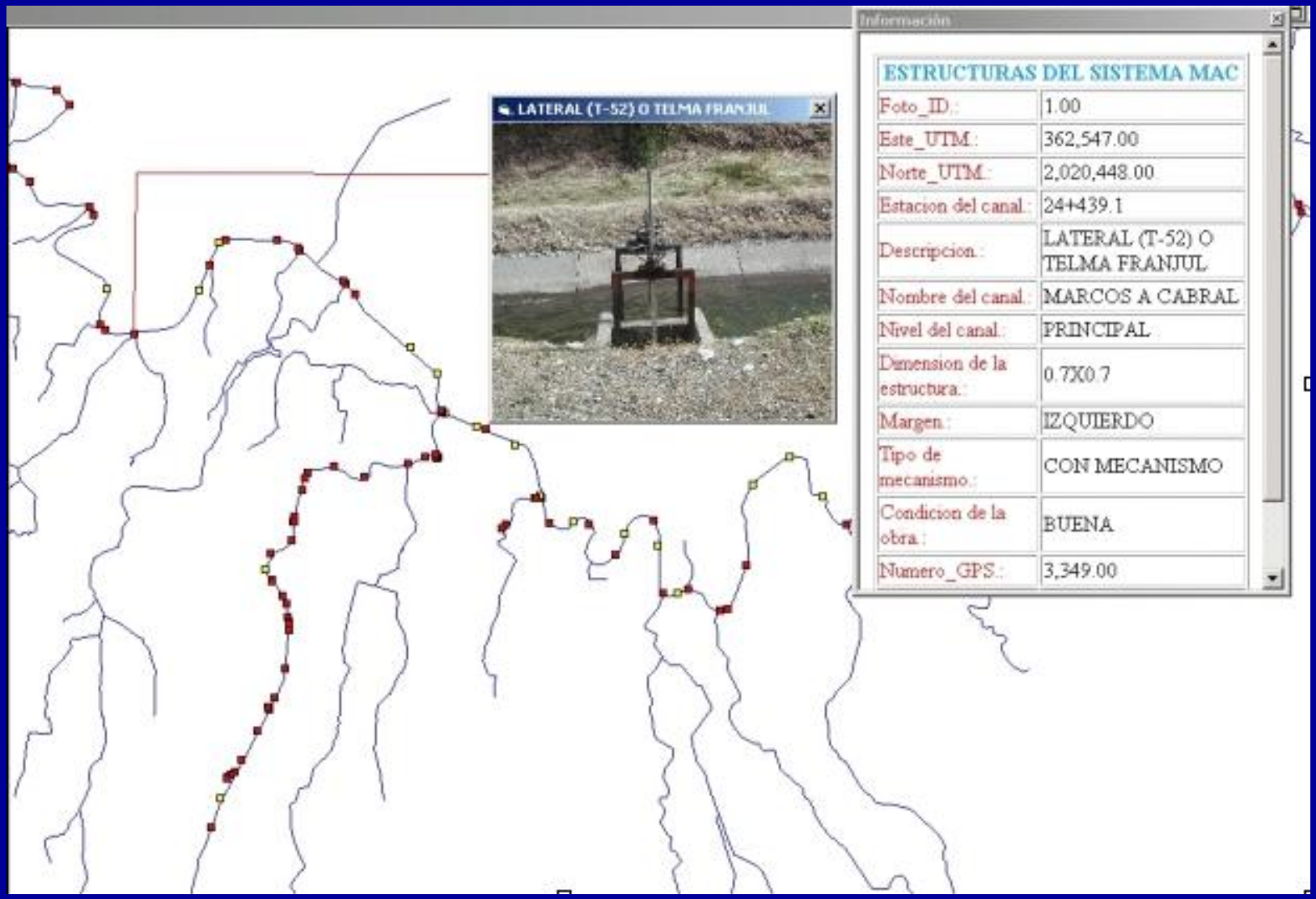
Irrigation Water Control Structures



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Canal Distribution GIS Layer

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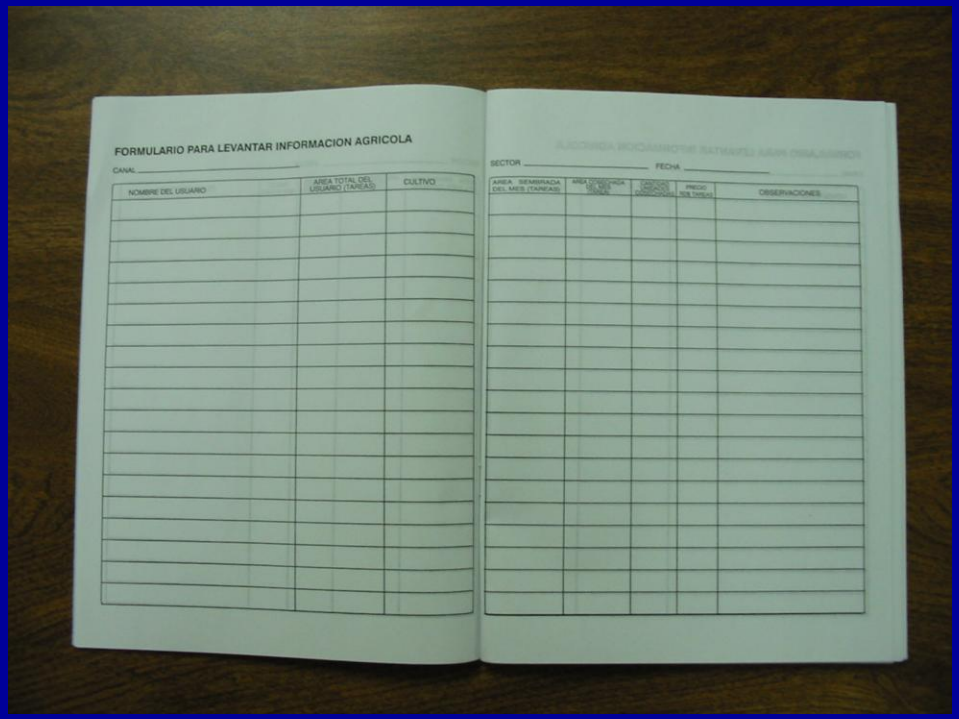
Before Estudios Basicos Project:

Agricultural Statistics Compiled Manually, with no map base



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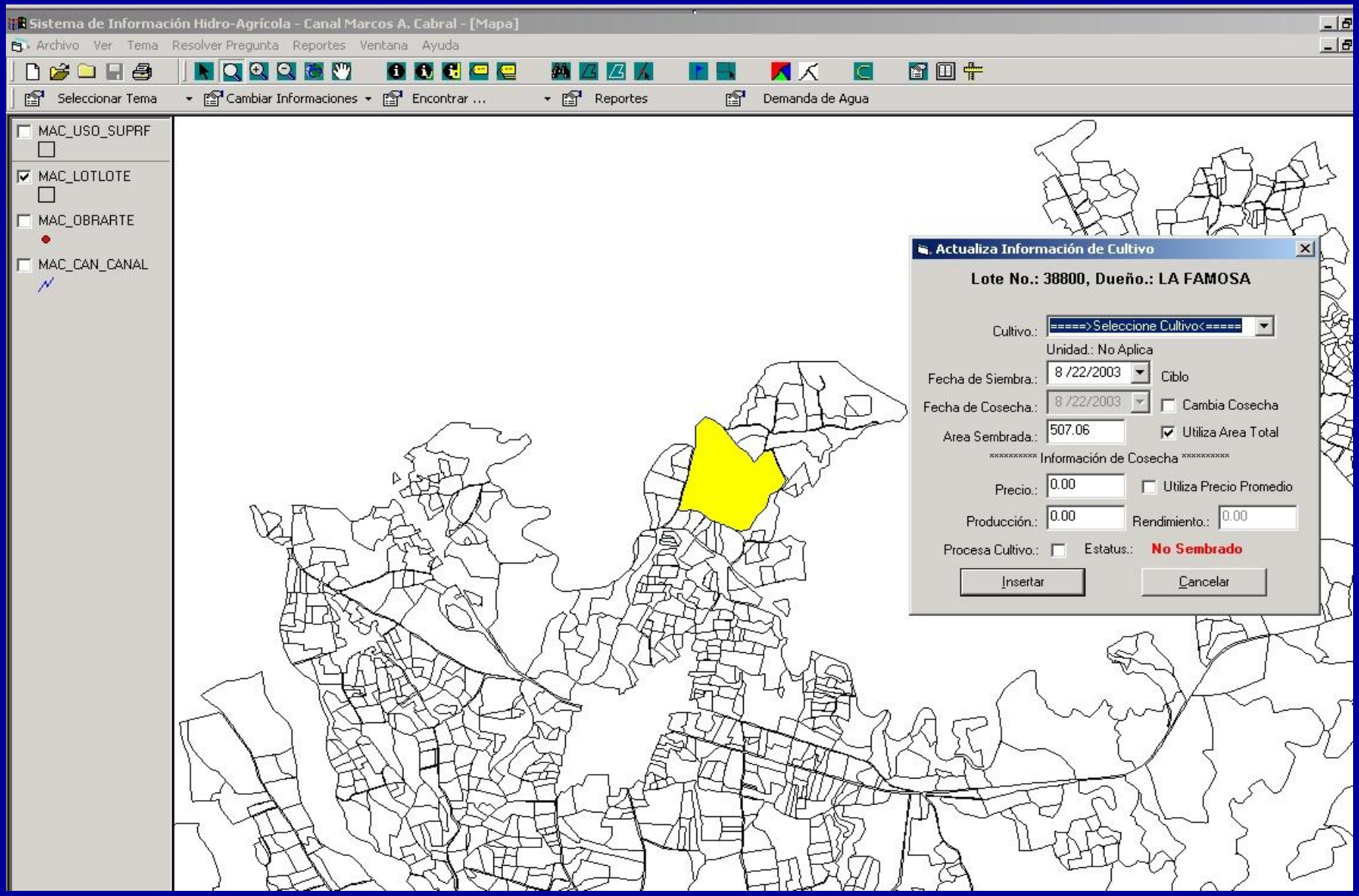
Presently: Crop Layer can be Easily Updated



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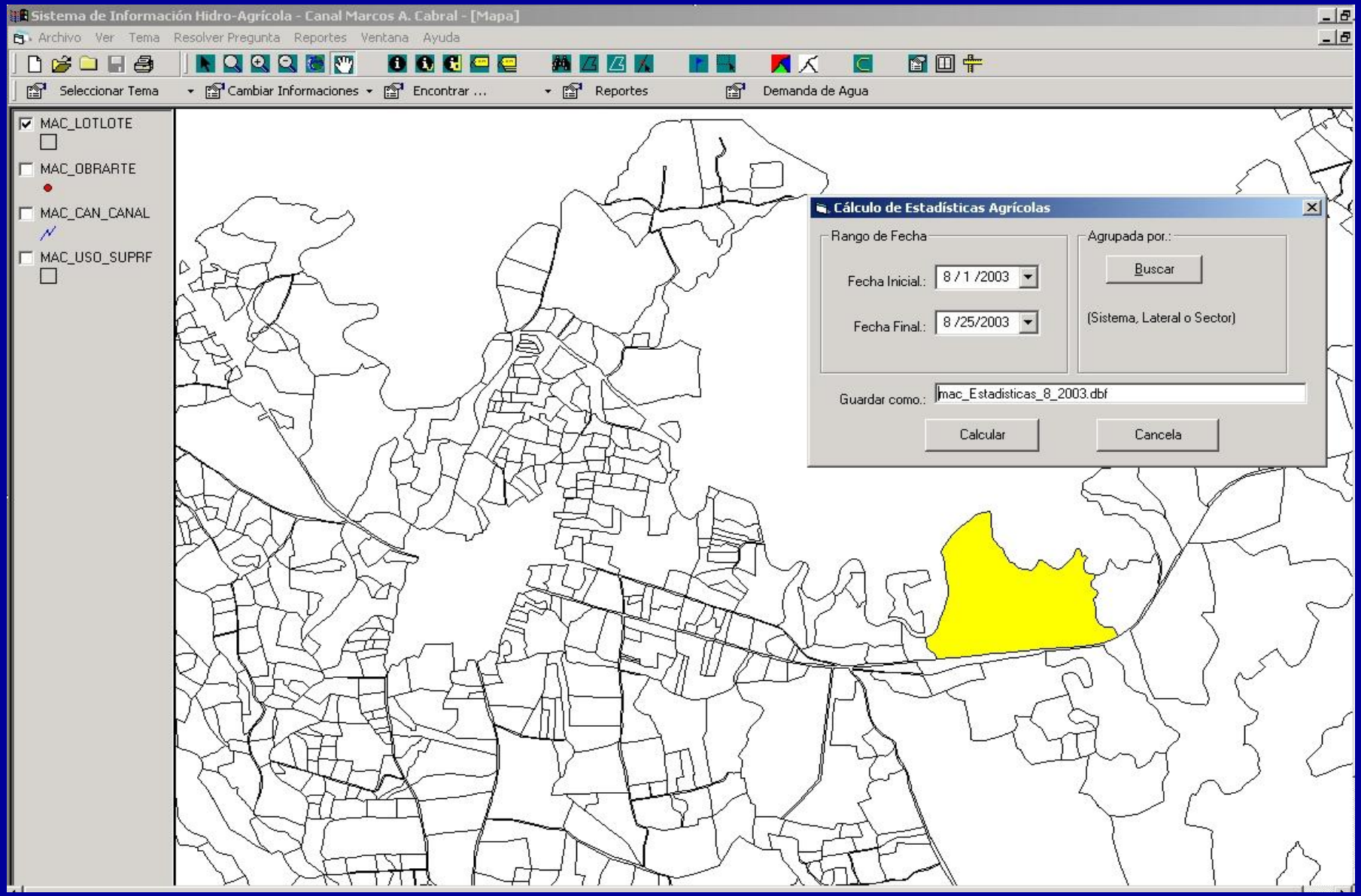
Calculation of Agricultural Statistics



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Training Activities:
Creation of the Geomatics Laboratory at INDRHI

- Repository of the printed and digital products developed though the project
- Care and protect the information in a climatized, safe environment
- Use the products and technical staff of the laboratory to support the different Departments of INDRHI
- Maintain and update the water users cadastre database by supporting the water users associations
- Development of a methodology for the expansion of the available digital cadastre for the entire country

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Present Situation

- A modern geomatics lab with state-of-the-art hardware and software and well-trained technical staff serving the institution

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Training Strategy

- Combination of short and medium term training
- 6 Technicians and Engineers were trained in Utah: Geographical Information Systems (GIS), Image Processing, Computer Programming (Visual Basic, Avenue), Development of the products: water users database and agro-hyrdological software
- Additional technicians were trained in Santo Domingo by USU
- Side-by-side training with direct participation in the production
- Responsibility for coordination with the Water Users Associations
- Responsibility for future training

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Training of Water User Association Personnel and INDRHI Irrigation District Personnel

- Basic Windows: 4
- Use of the Agro-hydrological System software: 4
- Updating the Water Users Database: 4
- Updating the Agricultural Statistics: 4

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Training of Personnel from the Soil and Water Division of INDRHI on the use of the Hydro-agricultural System Software

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Services Offered by the Geomatics Laboratory at INDRHI

- Sale of contact prints of the aerial photographs to the public
- Support to the different Departments of INDRHI in the production of maps, geomatic products, GIS and verification of cartografic information
- Support to different institutions in the agricultural sector of the country

Goal => Offer the products for sale over the internet, sale of the digital products, sale of value added products to generate funds to keep the laboratory equipment updated and protect products

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Final Observations

- The Geomatics Laboratory at INDRHI with its highly trained technical personnel and serving as a repository for all digital and printed products supports the different departments of INDRHI and the general public and has the capacity to offer services to other goverhment institutions.
- Became a new Department at INDRHI called the Department of Digital Cartography

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Final Observations

- The use of the digital cadastre of irrigators and related database by the transferred Water User Associations increased their O&M assessment inputs by up to 70% is some cases

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Another Example:
Bear River Canal Company

The irrigated area is located in northern Utah

30 Km west of Logan (Tremonton)

within the Bear River Basin

Bear River Basin

- A closed basin of 19425 Km2 bridging

3 states: Utah, Wyoming and Idaho

Bear Lake
1.75 Billion m3

Great Salt Lake
1280 m elev.
330 mm precip.

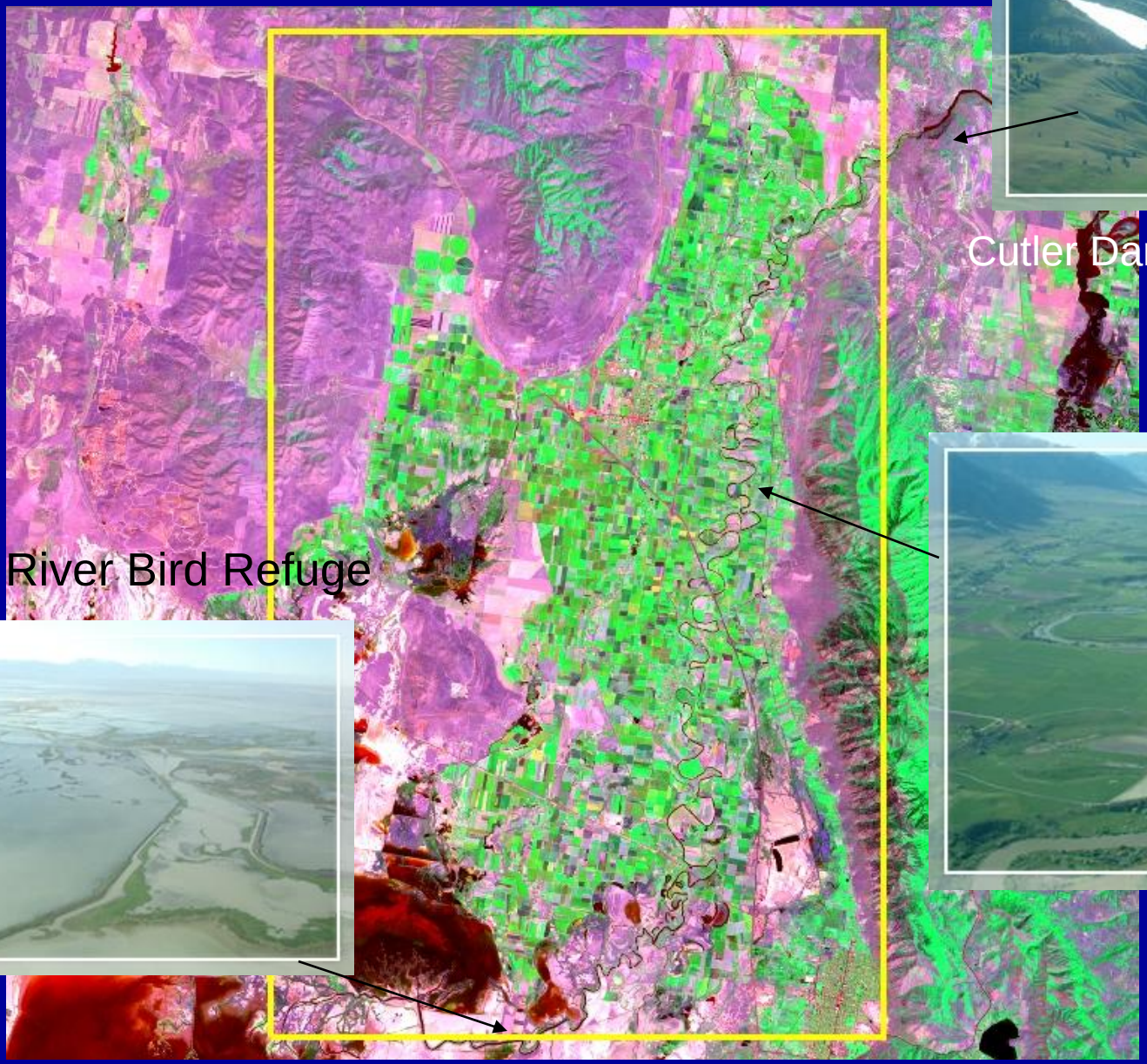
High Uinta Mountains
3900 m elev. 1140 mm

Bear River Canal Company History

- Water right on the Bear River was secured by the U&I Sugar company in March 1889 for 333 cfs (9.4 m^3/s)
- Irrigated area was expanded with the formation of the Bear River Canal Company and obtaining additional water rights
- Duty of water: 4 acre-feet / acre
- Priority right from 1st of April to 1st of October
- Bear River Bird Refuge downstream has priority right after 1st of October

Bear River Canal Company
27000 ha of Irrigated Agriculture

Cutler Dam and Canal Intake



Bear River Bird Refuge

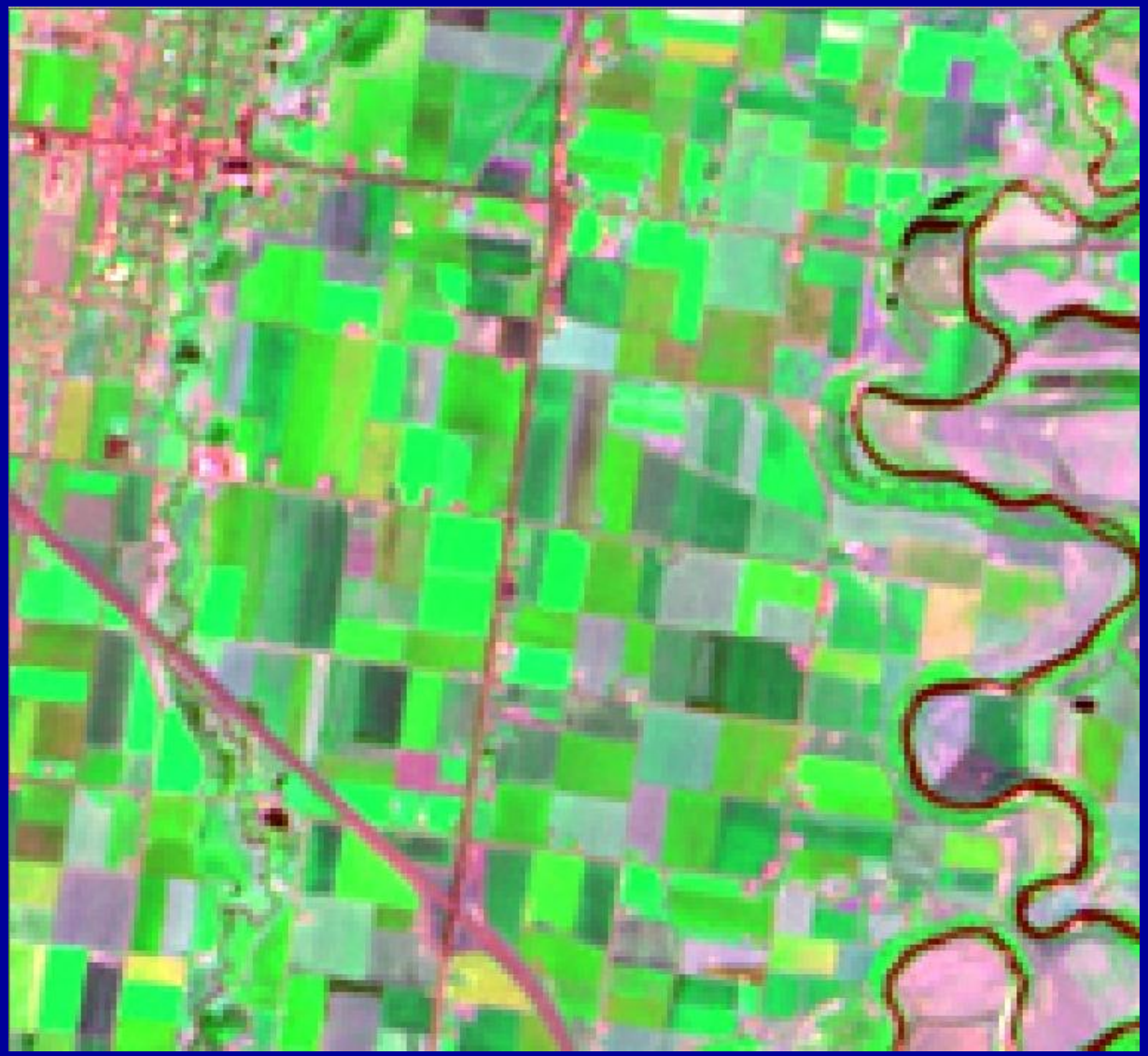
Irrigation System Characteristics

- Irrigation water diverted from Bear River into main canal at Cutler Dam
- 240 Km of mostly unlined earth canals
- Total diversion: 27 m^3/s through west canal (22 m^3/s) and east canal (5 m^3/s)
- Command area served: 27000 ha
- Delivery to farm turnouts on a 7- day fixed rotation basis
- Furrow and border surface irrigation
- Annual precipitation: 500 mm, mostly in the form of snow and spring rainfall

Diversion at Cutler Dam to Main Canal two canals: left and right of Bear River

Main Crops: alfalfa, corn, wheat, pasture, onions

Growing season: April to September



Water Management Issues

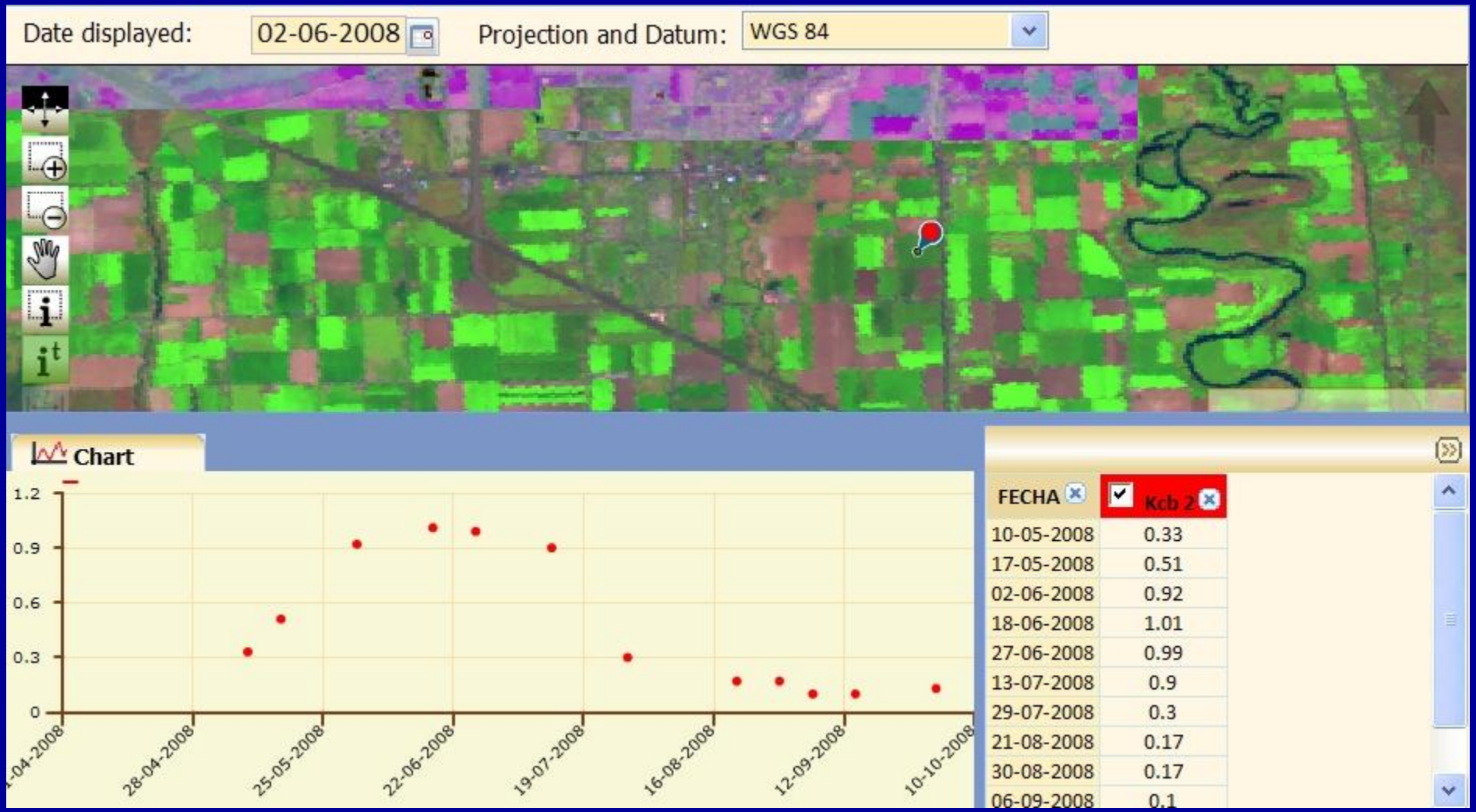
- 75% of irrigation water demand is supplied by natural flow of the river
- Some water stored upstream in Bear Lake (up to 230000 acre-feet) is available for use in late season (51% for Bear River CC)
- Usually start drawing from the lake in mid-June
- Shortages of water mid to late season in dry years (2004 they started drawing from lake on 8th of April)
- Some water conflicts with downstream users in the past (Bear River Bird Refuge)

Water Management Issues

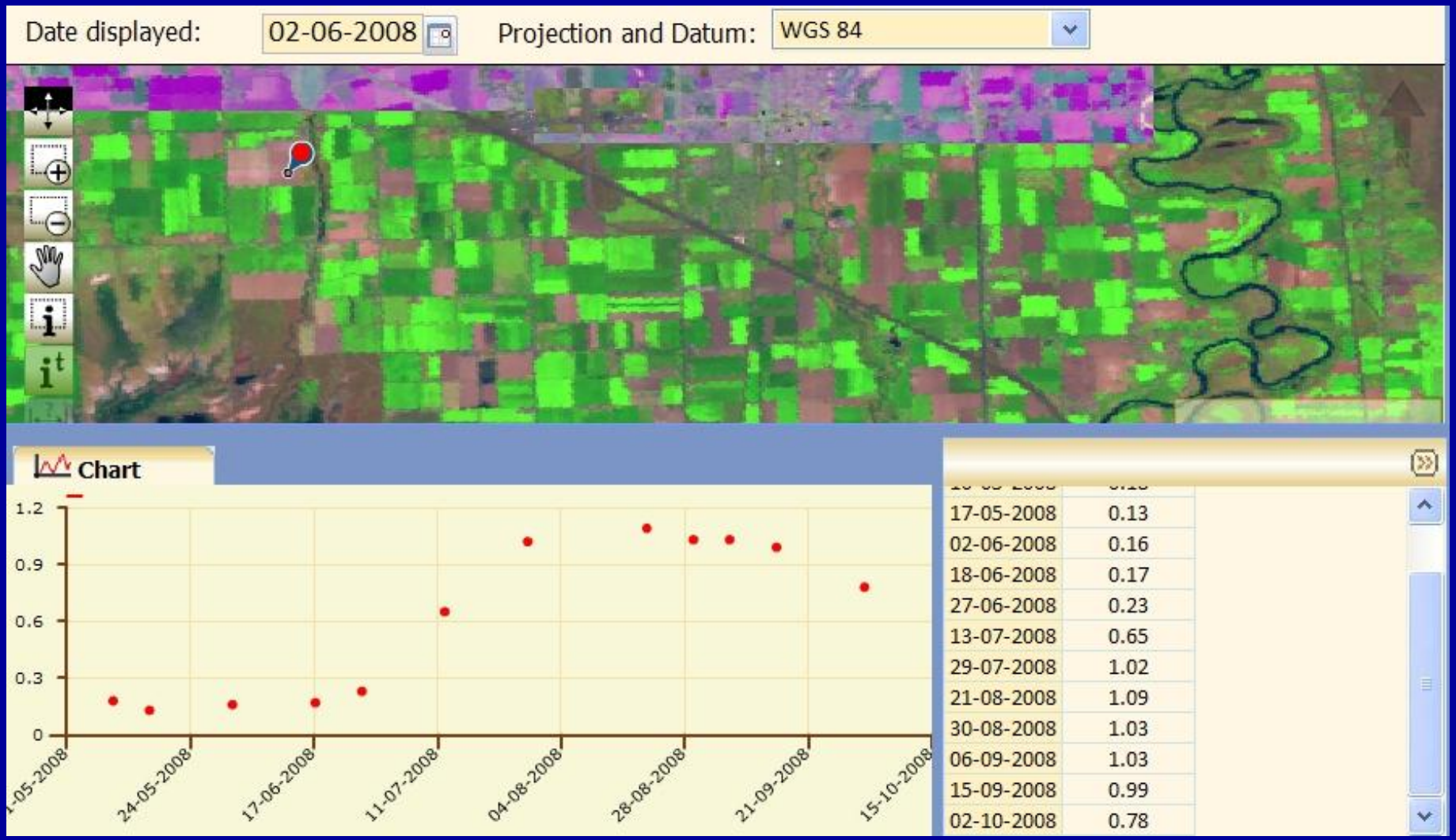
- Little incentive to improve irrigation efficiency due to low value of crops, the existing system of water rights, the low cost of water. Presently, the return flows from the system are used downstream by the Bear River Bird Refuge
- Operation and Maintenance fees for each share US$12/acre (1 share = 1 acre @ 4 acre-feet) or

  US$29.6/ha for 1220 mm of water or $0.0024/m3
- Other systems in the area: West Cache $22/acre; Cub River: $40/acre (pressurized)
- If additional water savings could be stored in Bear Lake for use in dry years, this could be an incentive to improve efficiency of the system to guarantee yield of crops in dry years or under persistent drought conditions

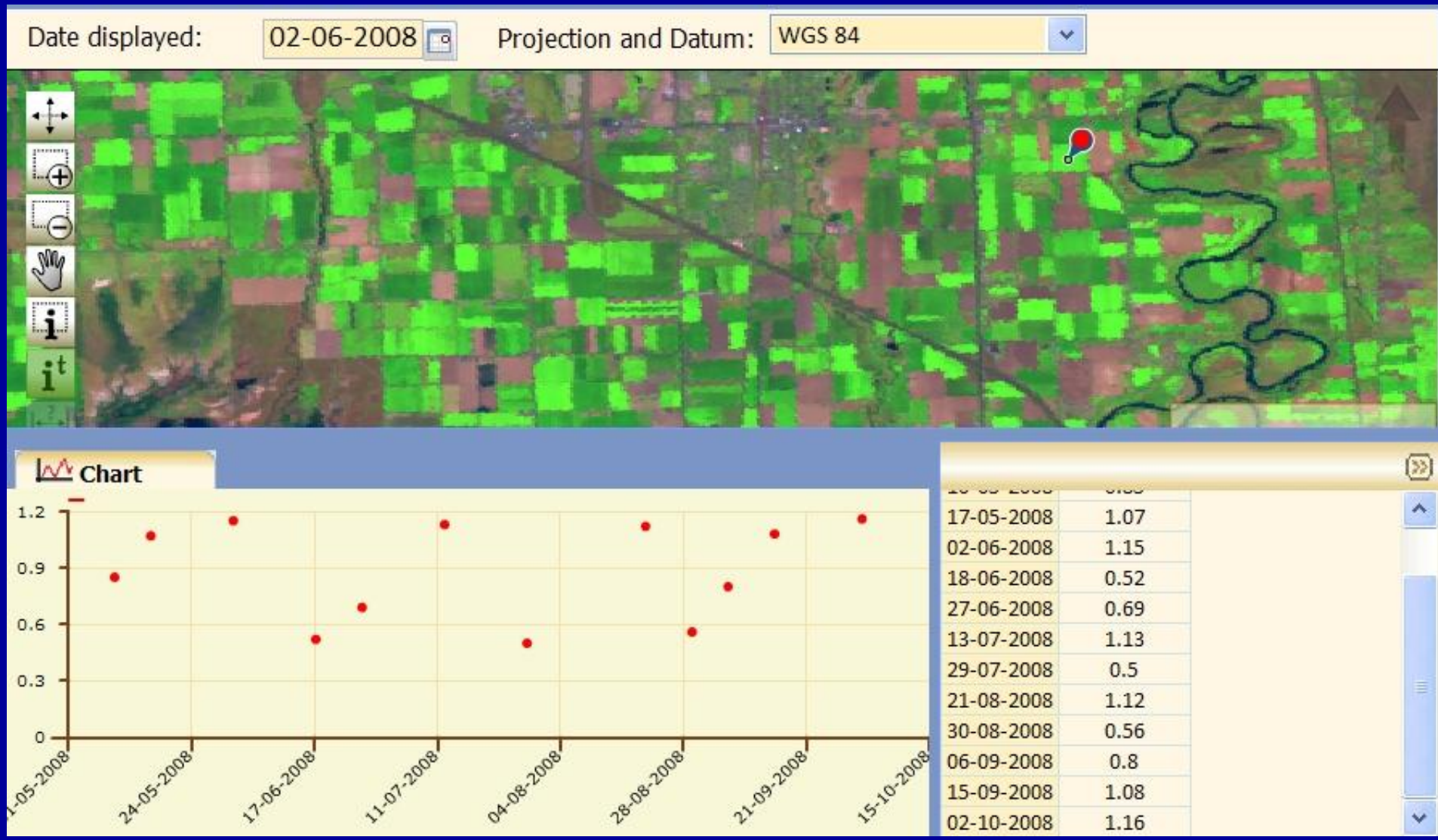
Wheat growing season: April through July



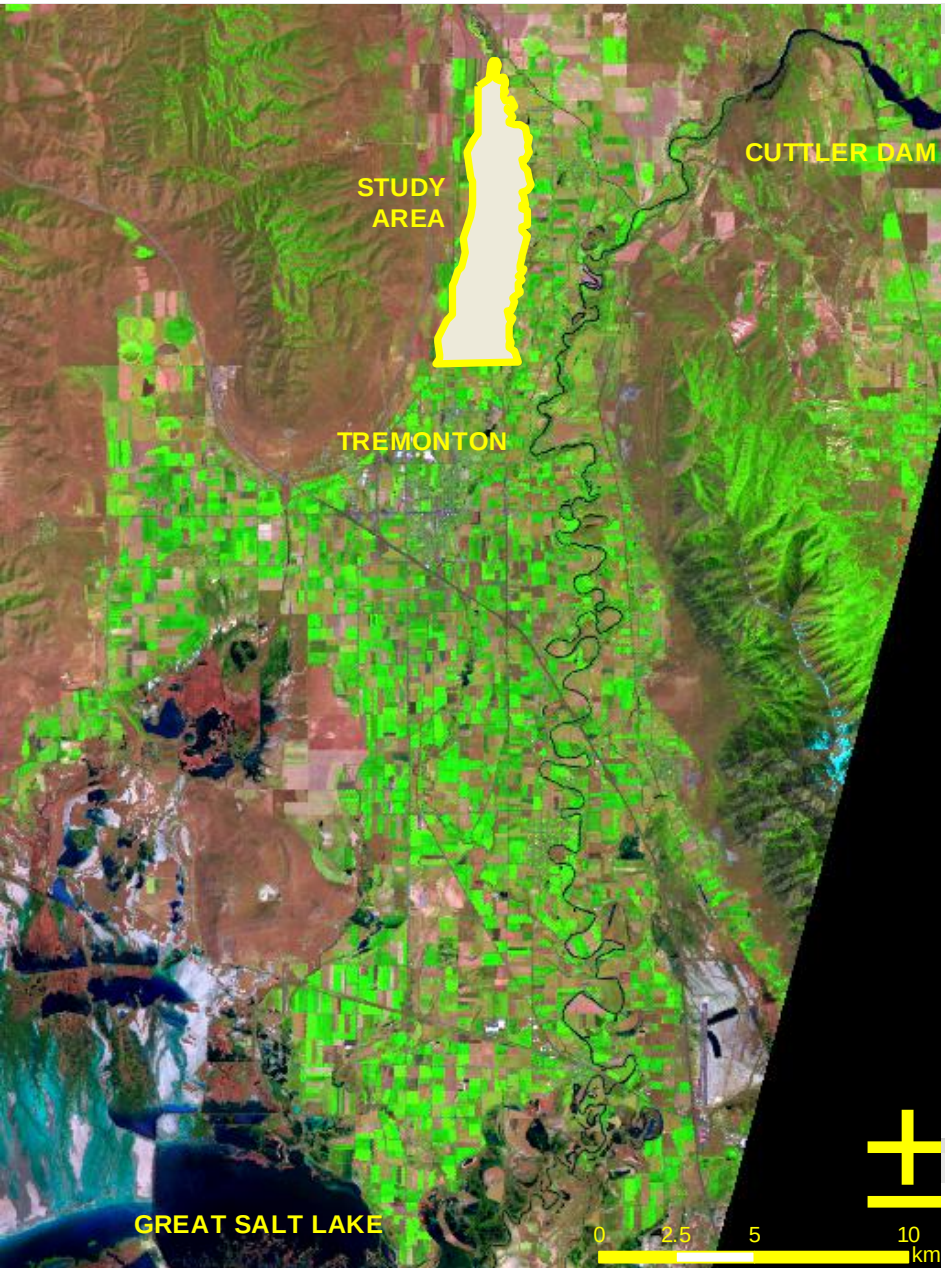
Corn growing season: May through September



Alfalfa growing season: April through October



ADOR Model Simulation



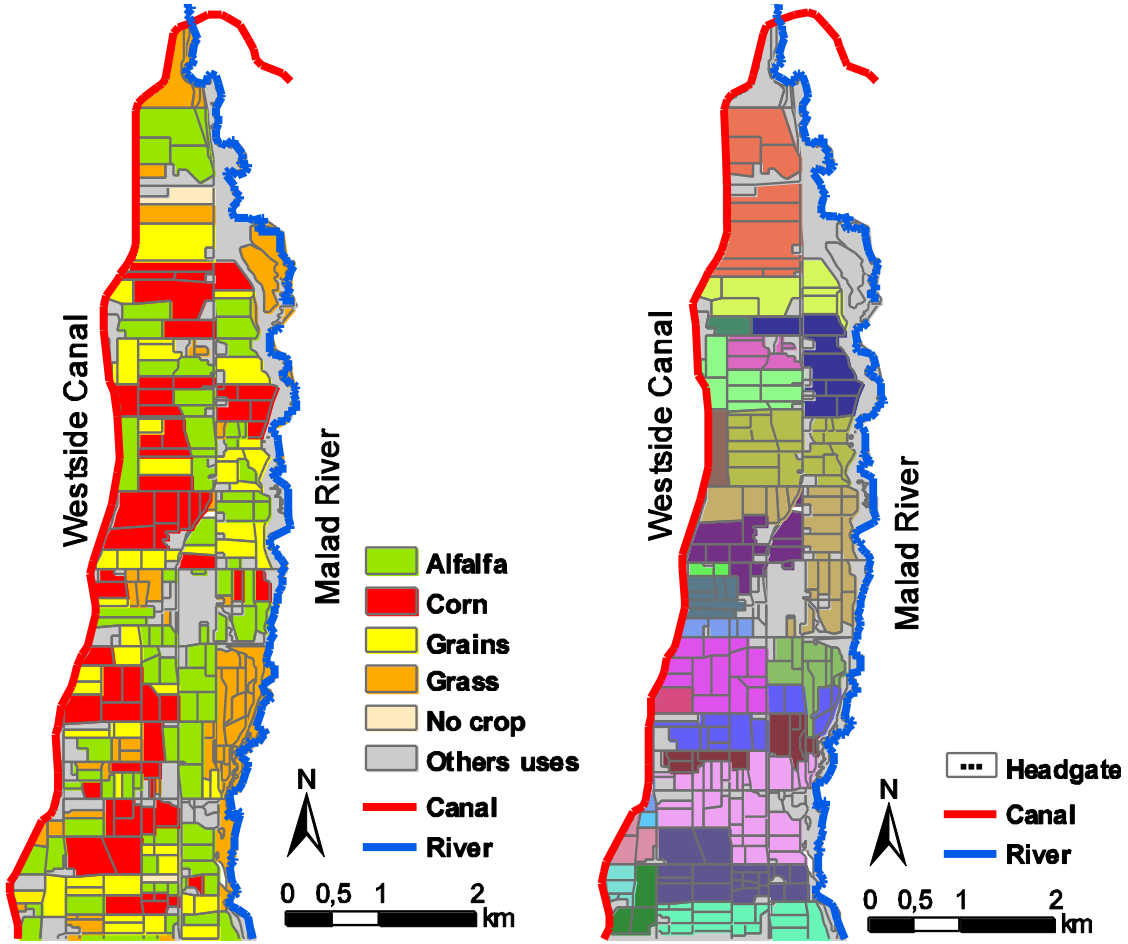
1. Selected study area.

- **1.213 ha** of irrigated area.
- **24 headgates** at Westside Canal.
- **79 land owners**.
- **130 plots**.
- **Rotation** water delivery.
- **Field crops** (alfalfa, corn, grains).

Figure 2. Study area

Material and Methods

2. Analyze structures, plots, crops…

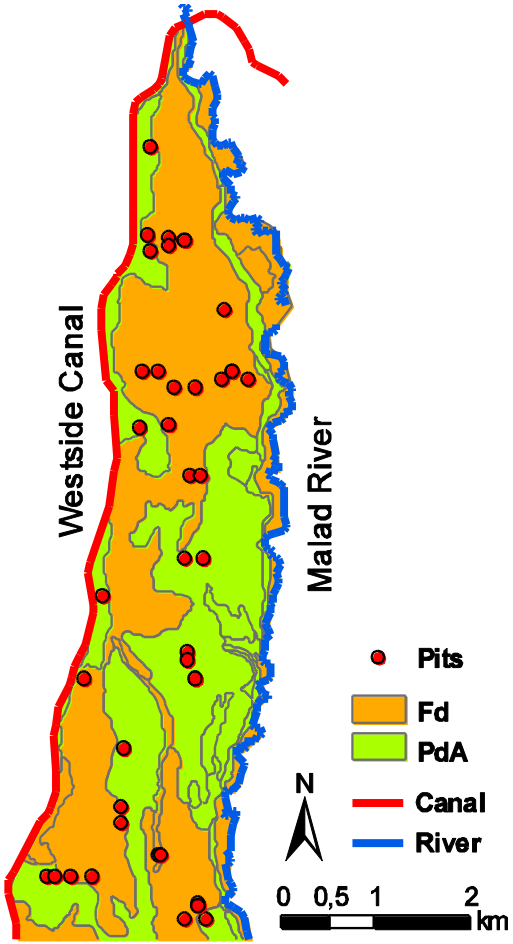


- 1.213 ha.
- 24 headgates.
- 79 land owners.
- 130 plots.
- 46 % alfalfa & grass.
- 32 % corn.
- 21 % grains.

Figure 3. Crops (left) and headgates irrigated areas (rigth)

Material and Methods

3. Study soils.

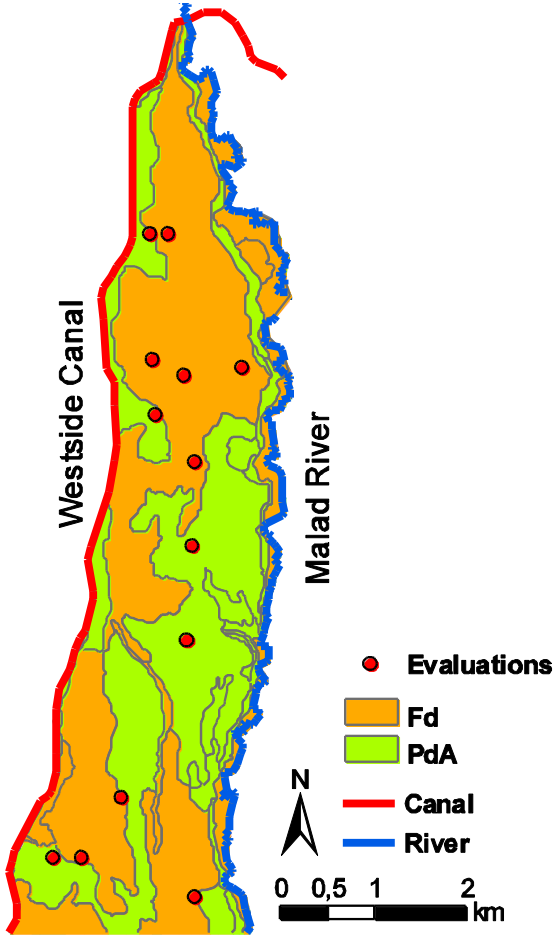


- **Parleys soils (PdA):** 44 %.
- **Fielding soils (Fd):** 56 %.
- **15 holes in PdA.**
- **21 holes in Fd.**
- **TAW was obtained.**

Figure 4. Location of the surveyed soil pits and soil map (NRCS)

Material and Methods

4. Evaluate irrigations.

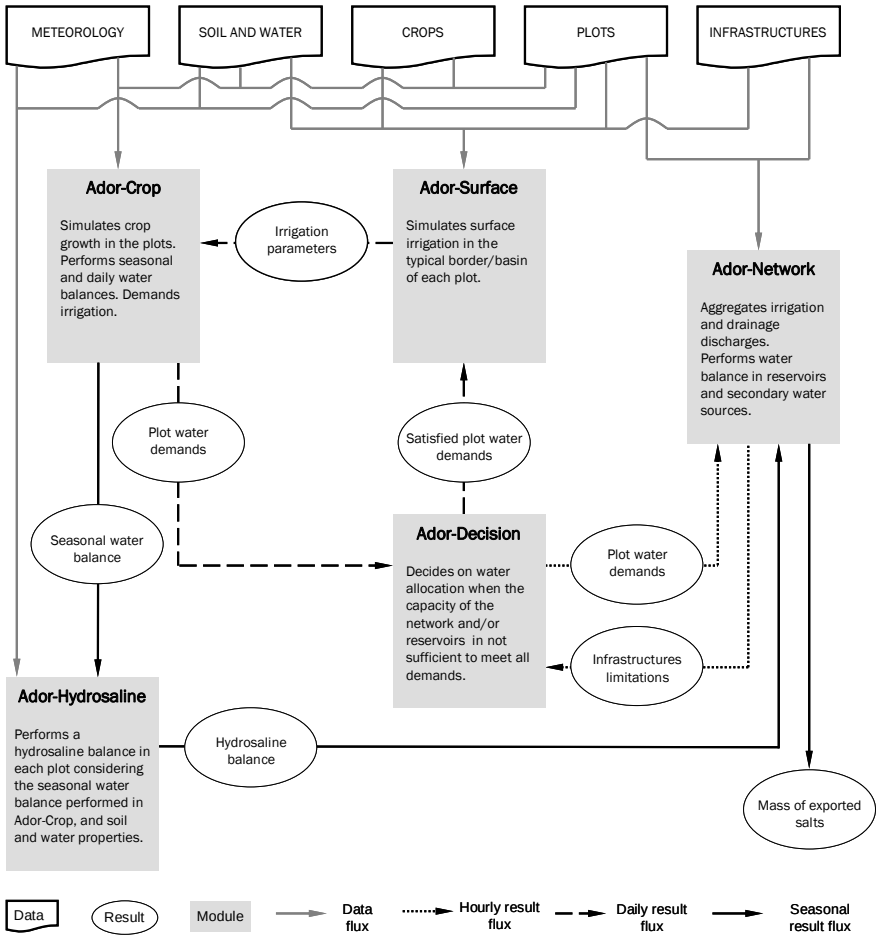


- 5 evaluations in PdA.
- 8 evaluations in Fd.
- Results obtained:
  - Infiltration equations.
  - Soil moisture before.
  - Irrigation time and depth.
  - Others features.
  - AE and DUlq.
- Sirmod model was used.

Figure 5. Location of the irrigation evaluations and soil map (NRCS)

Material and Methods

5. Simulate an irrigation season (2008).



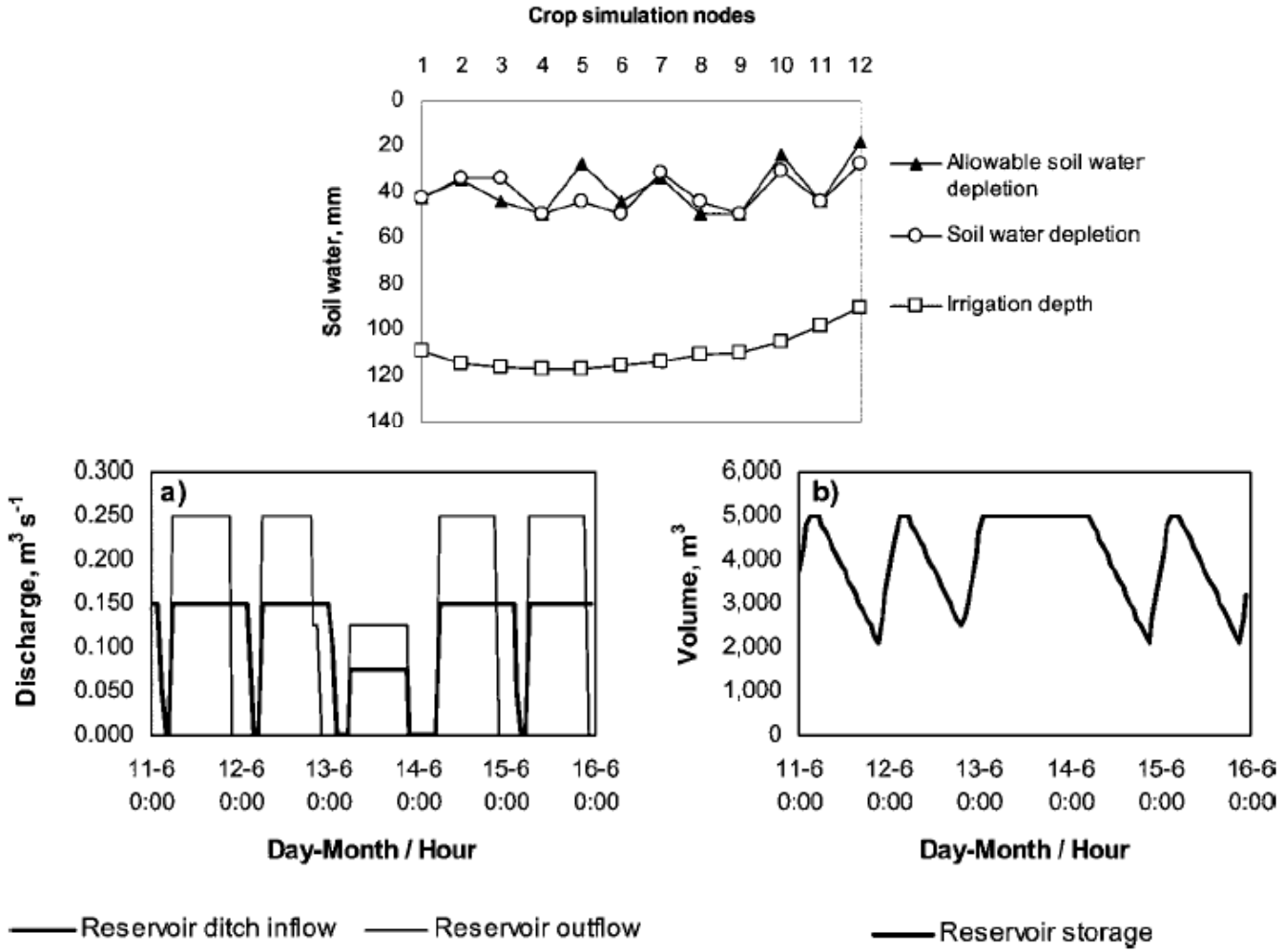
- **Ador-Simulation was used:**
  - **Weather.**
  - **Structures.**
  - **Soils and crops in plots.**
  - **Irrigations.**
  - **Water delivery.**
  - **Farmers and ditch riders.**

- **Irrigation, hydrological and economic indicators were obtained for:**
  - **Current scenario.**
  - **Optimized scenario.**

Figure 6. ***Schematic description of Ador-Simulation (Lecina and Payán, 2006)***

Material and Methods

Figure 7. ***Examples of outputs of Ador-Simulation in plots, ditches and reservoirs***



Results and Discussion

2. Irrigation evaluations.

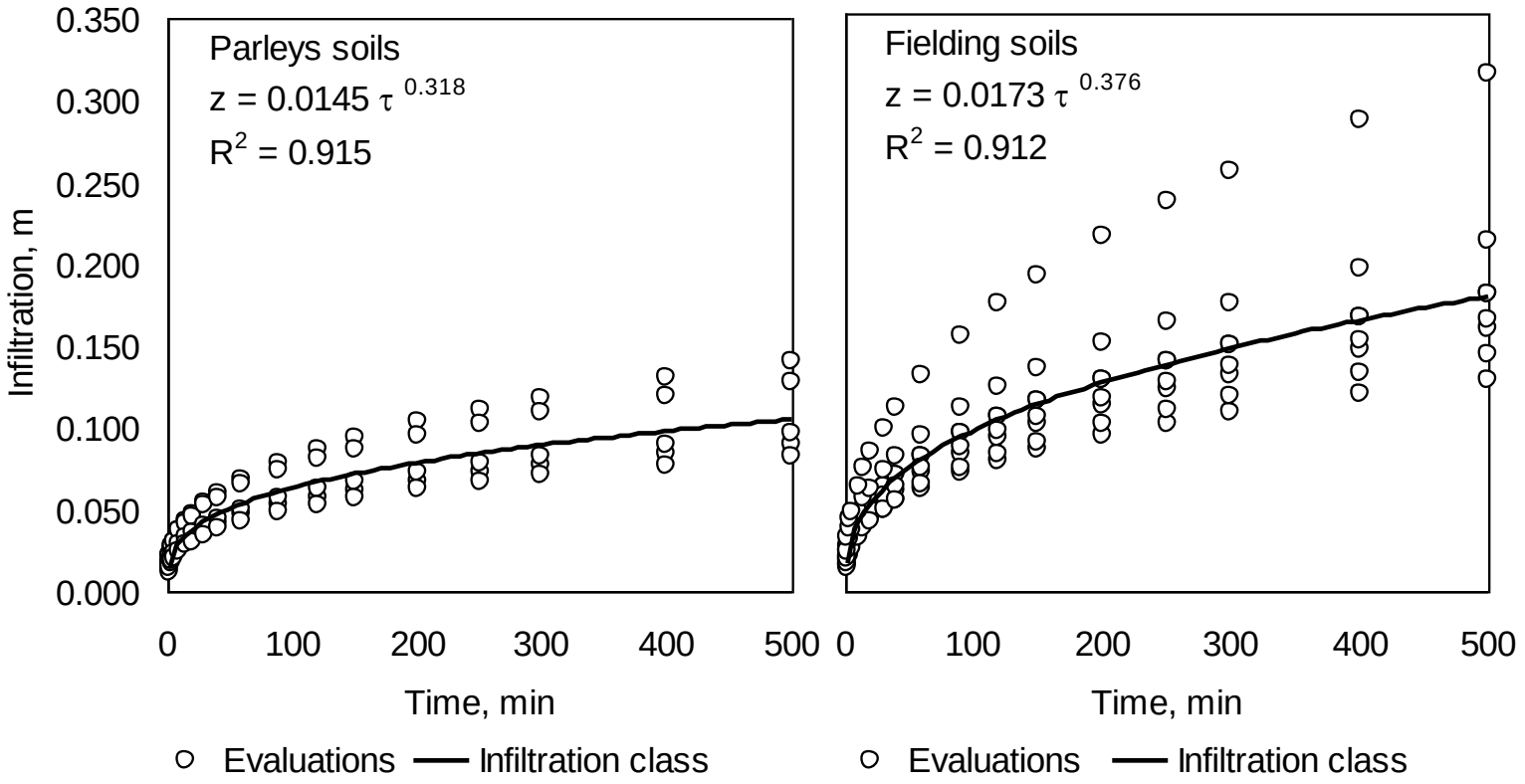
Table 2. Results of the irrigation evaluations

		Parleys soils	Fielding soils
Area (m^2)	Average	12,589	17,569
	CV (%)	47	21
Width (m)	Average	37	49
	CV (%)	17	20
Slope ($^{o}/_{00}$)	Average	1.89	1.48
	CV (%)	31	58
SDE (mm)	Average	13	16
	CV (%)	38	22
Discharge ($m^3\ s^{-1}$)	Average	0.091	0.091
	CV (%)	53	14
Irrigation time (h ha^{-1})	Average	5.70	7.18
	CV (%)	49	22
Irrigation depth (mm)	Average	144	230
	CV (%)	22	19

Results and Discussion

2. Irrigation evaluations.

Figure 8. ***Infiltration equation of each soil***



Results and Discussion

3. Irrigation season simulation.

Table 4. Irrigation indicators obtained through the application of Ador-Simulation for the current and optimized scenarios

	Current Scenario	Optimized Scenario
IRRIGATION INDICATORS		
Irrigation time, h ha^{-1}	6.8	4.6
Average Application Efficiency, %	53	74
Average Irrigation Efficiency, %	56	77
Average LQ Distribution Uniformity, %	62	75

Results and Discussion

3. Irrigation season simulation.

Table 5. Hydrological indicators obtained through the application of Ador-Simulation for the current and optimized scenarios

	Current Scenario	Optimized Scenario
HYDROLOGICAL INDICATORS		
Canal Water Demand, hm^3	12.27	8.96
Precipitation, hm^3	1.25	1.25
Water Use from Vadose Zone, hm^3	1.88	1.78
Crop Evapotranspiration, hm^3	9.55	9.59
Irrigation and Rain Return Flows, hm^3	6.25	2.90
Seasonal Soil Water Variation, hm^3	-0.40	-0.51
Consumptive Fraction, %	100	100
Productive Consumptive Fraction, %	60	77
Crop Evapotranspiration Reduction, %	9	9

Results and Discussion

3. Irrigation season simulation.

Table 6. Economic indicators obtained through the application of Ador-Simulation for the current and optimized scenarios

	Current Scenario	Optimized Scenario
ECONOMIC INDICATORS		
Crop Yield Reduction, %	14	12
Crop Gross Value Reduction, %	12	10
Crop Gross Value, M$	1.488	1.516
Crop Net Value, M$	0.504	0.532
Gross Surface Productivity, $ ha^{-1}	1226	1249
Net Surface Productivity, $ ha^{-1}	416	439
Gross Consumptive Water Productivity, $ m^{-3}	0.092	0.117
Net Consumptive Water Productivity, $ m^{-3}	0.031	0.041
Net Canal Water Productivity, $ m^{-3}	0.041	0.059

Ongoing Tasks

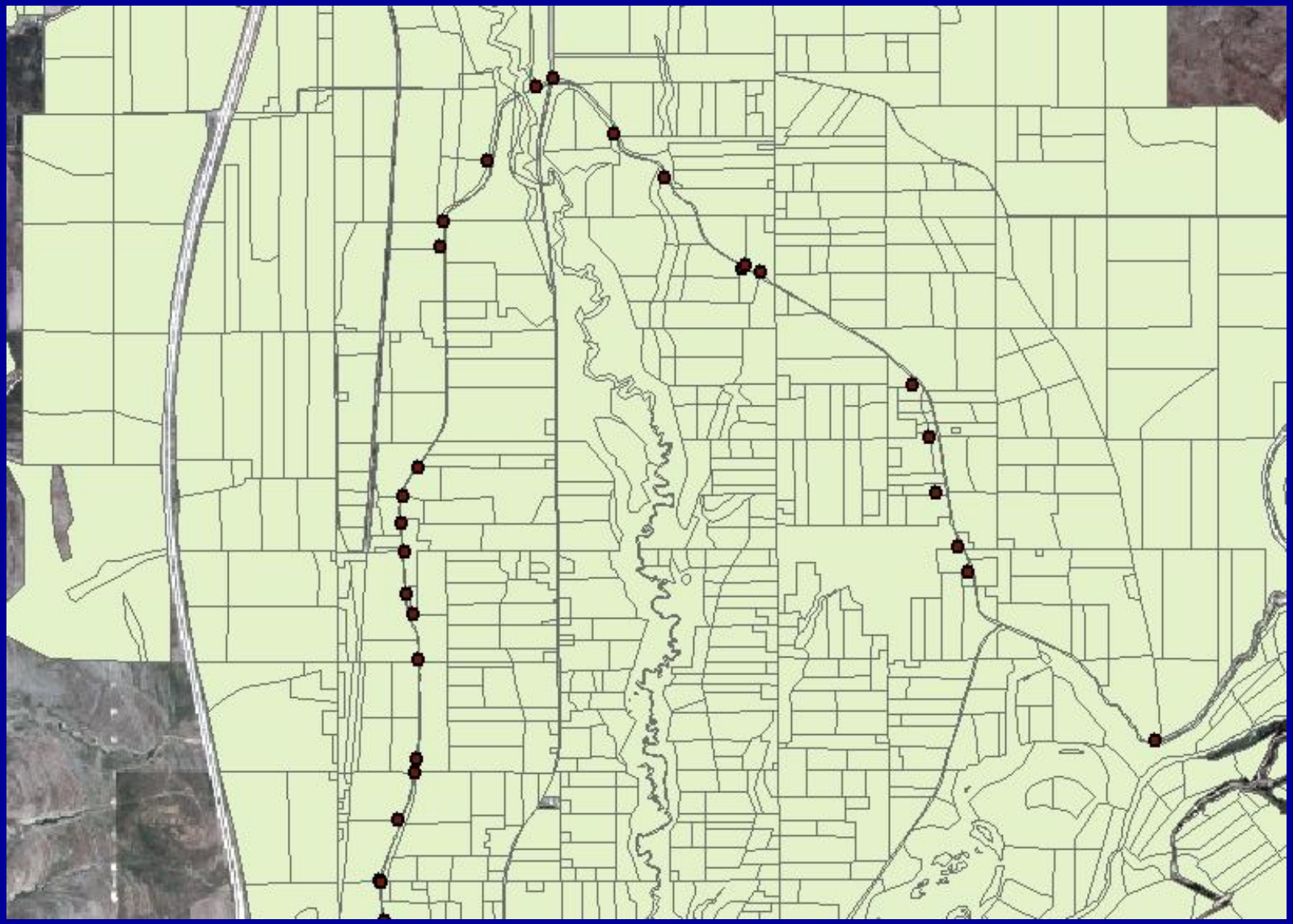
- The command area of laterals and tertiary canals for the entire system has been identified and digitized
- Position of the gates were also obtained
- Surface irrigation evaluations were conducted during the summer of 2009 on 6 other soils present within the irrigation system
- The ADOR model will be run on the entire system using remote sensing based basal crop coefficients

Bear River Canal Company GIS Database

NAIP Color digital orthophoto at 1-m pixel resolution base map

NAIP High resolution at 0.3 m pixels used to digitize location of gates and small tertiary canals

Some GIS Layers:
Canal Gate Locations and Water Users



Final Comments

- Cadastre of irrigation water users is a fundamental product required in the transfer of irrigation systems from government to private control
- Digital GIS based cadastre databases can be updated and modified to match conditions in the field
- Information on canal command areas, gates, crops obtained through remote sensing and GIS techniques can be used in models for analyzing system performance and efficiency.

Obrigado!