

The background of the slide is a dark teal color with a faint, repeating pattern of microscopic structures, possibly pollen grains or plant cells. A large, dark blue, circular shape with a pointed bottom edge is centered on the slide, serving as a backdrop for the text.

Applications of GIS Technology in Bio-Sciences.

By

Vuppaladadium, Naga Deepa

Objective

The presentation brings together two of the most dynamic analytical technologies—GIS and Bioinformatics.

The value of GIS analytical systems and data structures to Bioinformatics is only recently being recognized. Similarly, the methodologies used in Bioinformatics can inform GIS scholars of new approaches to pattern recognition and analysis. The purpose of the presentation is to explore the potentials for using GIS as an analytical methodology in Bioinformatics and to understand the opportunities Bioinformatics presents to the GIS research community.

Internship Details

- Where:
Center of Environmental Studies (CES) Department
of Arizona State University.
- As:
GIS Research Assistant.
- Employers:
Peter McCartney and Brenda Shears

Internship Requirements

The basic requirements for the internship at CES was having an understanding of some or all of the following:

- Programming: Visual Basic 6, SQL, Java 2, XML
- Software Packages: ArcGIS, ArcCatalog, ArcMap, ArcInfo, Adobe Photoshop, SPSS.
- Databases: MS Access, SQL Server
- Others: Knowledge of Math, Biology, Ecology, Geography.

Nature of Work

Category 1

Worked as an instructor for BIO591 Social Environmental Aspects of Irrigation Systems.

- Part-1: Pre-historic analysis of canals systems for irrigation.
- Part-2: Modeling the soils of Arizona and Mexico.

Category 2

Assisted the environmentalists and software programmers in creating maps and metadata.

- Part-1: Creating Maps and layouts.
- Part-2: Updating metadata on the website <http://www.gp2100.com/eatlas>

Literature Review

The review has been divided into four sections.

3. Overview of the BIO591 course and the related project in sc
5. Prehistoric canal systems project.
7. GIS concept and its applications.
9. Metadata, maps and its uses.

Bio591 Course

BIO 591 in Life Sciences Department of Arizona State University was a course offered in Fall 2003 for students who were interested in studying the environmental aspects and the social aspects involved in irrigation systems in Arizona and Mexico.

Dr Jason and his group of students were interested in developing a model of soils and crops that followed certain production patterns. They were also interested in doing a comparative study for the Mexico soils.

The research focuses on feedbacks between terrestrial ecosystems and environmental change. Many of these feedbacks are driven by changes in biogeochemical cycles, i.e. changes in the storage and movement of energy and nutrients in the Earth system.

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Prehistoric Canal Systems.

- Hohokam land-use practices provides an insight into how large populations can live sustainably in dry lands. The Hohokam did it from at least 500 to 1450 A.D. by being farmers and environmentalists at the same time.
- Hundreds of miles of prehistoric canals in the Salt, Gila, and Santa Cruz river basins are the most dramatic evidence of the Hohokam's sophisticated management of their crucial water resource.
- In addition to growing crops, such as corn, cotton, and tepary beans, the Hohokam also gathered a variety of plants from the surrounding desert. Many Hohokam land-use practices amounted to a sort of environmental protection plan. Hohokam irrigation systems provided a sustainable source of soil fertility.

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GIS Technology

- What is GIS?

It is a particular form of Information System applied to geographical data.

- In GIS, the common purpose is decision-making, for managing use of land, resources, transportation, retailing, oceans or any spatially distributed entities. The connection between the elements of the system is geography, e.g. location, proximity, spatial distribution.

- There are several areas where GIS can be applied. Some of the major areas of practical application of GIS Technology, in Natural Resource area are forest management, wildlife habitat, migration routes management, wild and scenic rivers preservation, floodplain management, Wetland preservation, Agricultural lands management, Health Care, Groundwater modeling and contamination tracking, Environmental impact.

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Maps and Metadata

Maps: What Are They?

Maps depict, most commonly on a flat surface, the spatial organization of any part of the physical universe at any scale, and at the same time symbolize a wide variety of information, both static and dynamic.

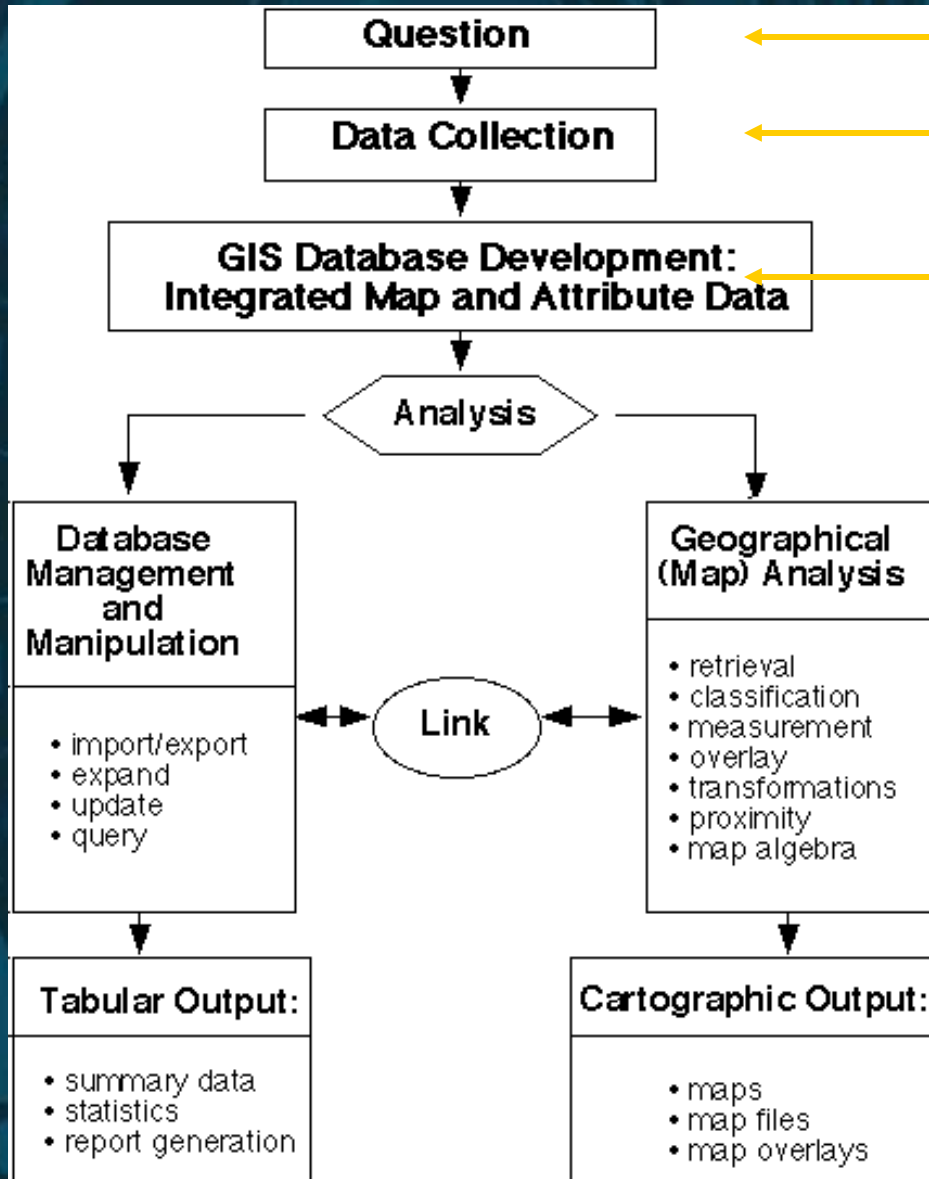
Metadata or "data about data" describes the content, quality, condition, and other characteristics of data. Metadata are simply descriptive information applied to a digital geo-spatial file. Metadata utilize a common set of terms and definitions to document geo-spatial data.

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Methodology and Analysis

- Implementing GIS.
- Production of Crops Model.
 - Logistic Model
- Model of the pre-historic canals systems for i
 - Taylor Series Expansion.
- Creating Maps.
- Writing Metadata.

Flow Chart of GIS



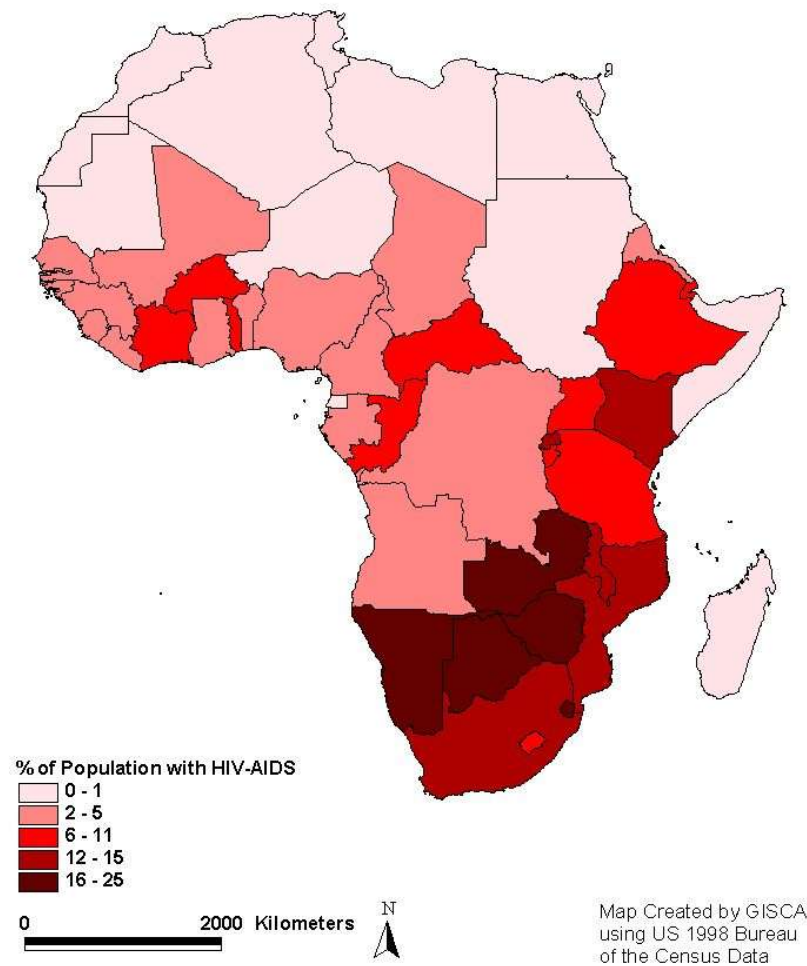
An initial geographic question drives the data collection. Example: Spread of infectious diseases like HIV/AIDS. Commonly data collection is done by either manually digitizing data from appropriate maps or by importing tabular data. The data is then converted to a digital format and is entered into a database where it is stored as integrated map and attribute data.

The analytical process then manipulates both map and attribute data through the linkages that GIS establishes between them

Two types of output are common: tabular (summary data, statistics, reports) and cartographic (maps, map files, and map overlays).

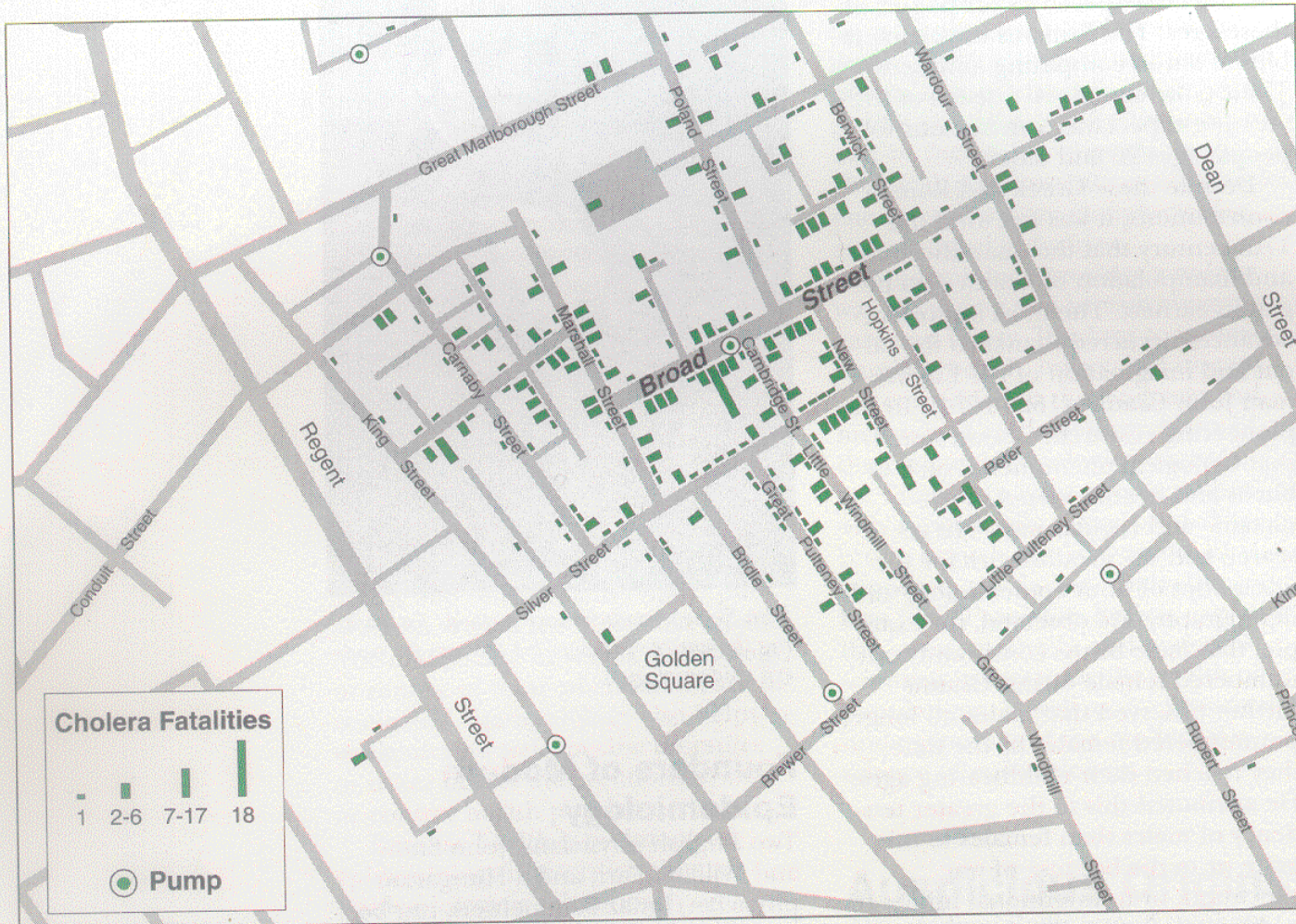
GIS Applications in Health Care

Figure 1
Africa
Countries classified by
% of population with HIV-AIDS



- GIS activity is flourishing at CDC and the Agency for Toxic Substances and Disease Registry (ATSDR).
- Remotely sensed and Global Positioning System (GPS)-related technologies are used worldwide in the environmental effort to prevent malaria, onchocerciasis, trypanosomiasis, schistosomiasis, guinea worm and dengue fever.
- Geo-referenced tools are used nationally to study patterns and better hypothesize associative environmental covariates of Lyme disease, cancer mortality, respiratory diseases, childhood lead exposure, and arboviral and La Crosse encephalitis, as well as health effects of hurricanes, earthquakes and floods.

Cluster Map of Fatal Cholera Cases in London, 1854



Source: Adapted from John Snow, *Snow on Cholera* (New York: Hafner, 1965).

Statistical Analysis

Statistical Analysis

- Can use GIS to explore statistical analysis of data
 - Eg 1: Display outlier or influential cases by location
 - Eg 2: Use cluster detection methods for influenza surveillance
 - Eg 3: investigate disease clusters in time and space
 - Eg 4: detect change in frequency of case occurrence
 - Eg 5: use as an alert
- Statistical analysis also useful in finding zones of high disease prevalence.

GIS Answers them

A few typical questions that can be answered by GIS are:

- Can we identify areas wherein a particular disease is prevalent?
- Can we get some clues about the possible factors that is responsible for a particular disease?
- Where to give additional sanctions for facilities and staff?
- Where to locate a Primary Health Center?
- Which are the areas wherein water related diseases are prevalent ?
- In which area the infant mortality rate is high?
- Which are the areas where the birth rate is high?

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Soil Analysis and Crops Model

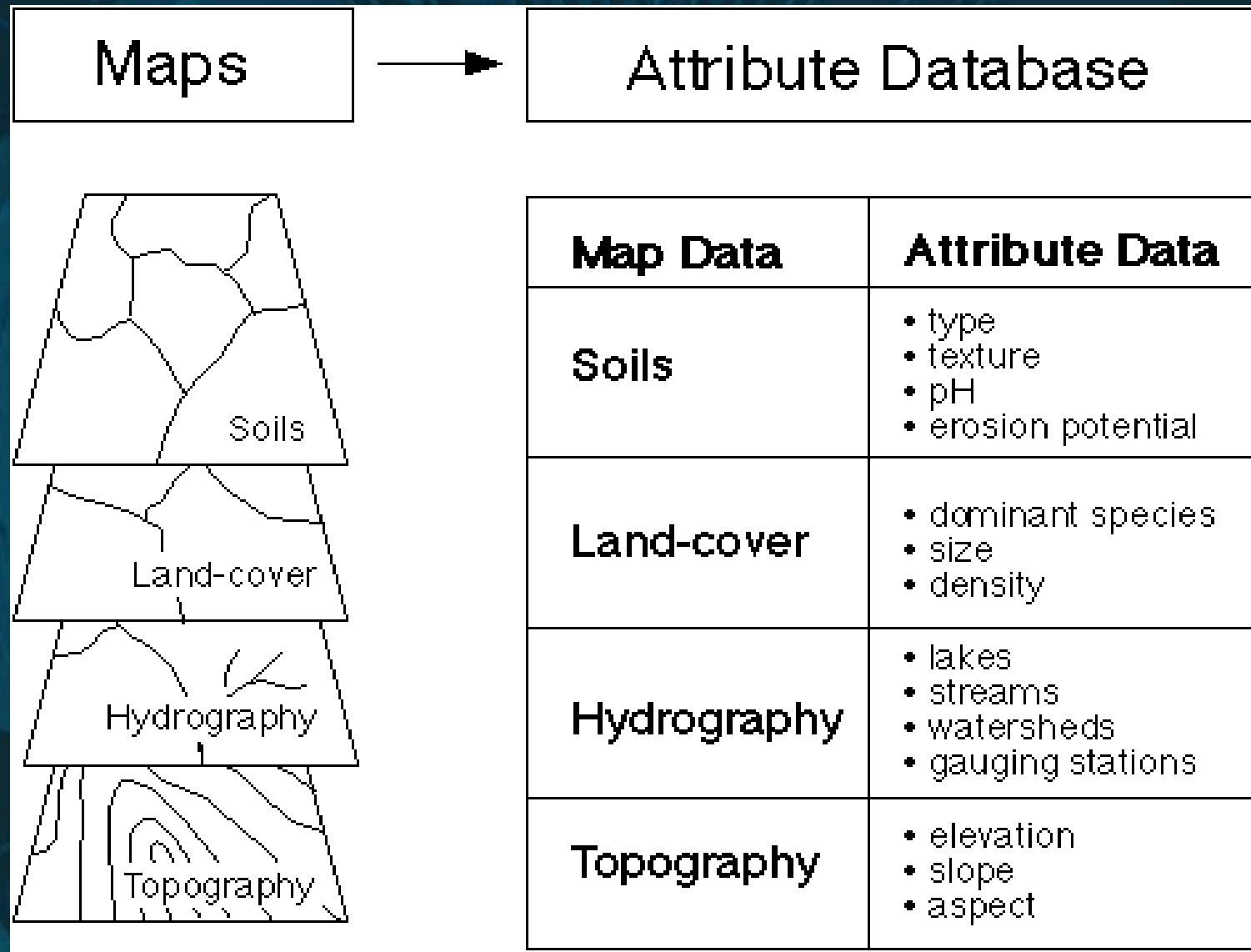
Initially students collected the soil data from fields, websites, laboratories and other resources.

The data is formatted and stored as datasets in GIS database. Each dataset typically consists of several attributes like soil name, soil type, soil key, soil texture, slope of the ground, moisture content, PH content, flooding frequency, hydrology, etc.

The GIS database contains both map data (depicting location of geographical objects) and attribute data (such as soil type, soil texture, PH content, moisture content) and/or non-physical characteristics (such as estimated soil code, key).

During a GIS analysis, site (map) data is linked with situation (attribute) data for each mapped timber stand [5]. It is this link, which is automatically performed by the GIS software, which gives GIS its analytical power. See Figure

Map data \longrightarrow Attribute data.



Continued..

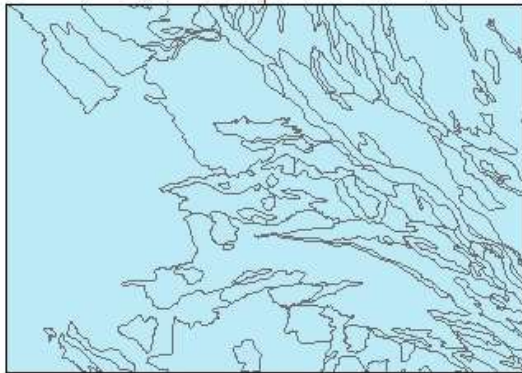
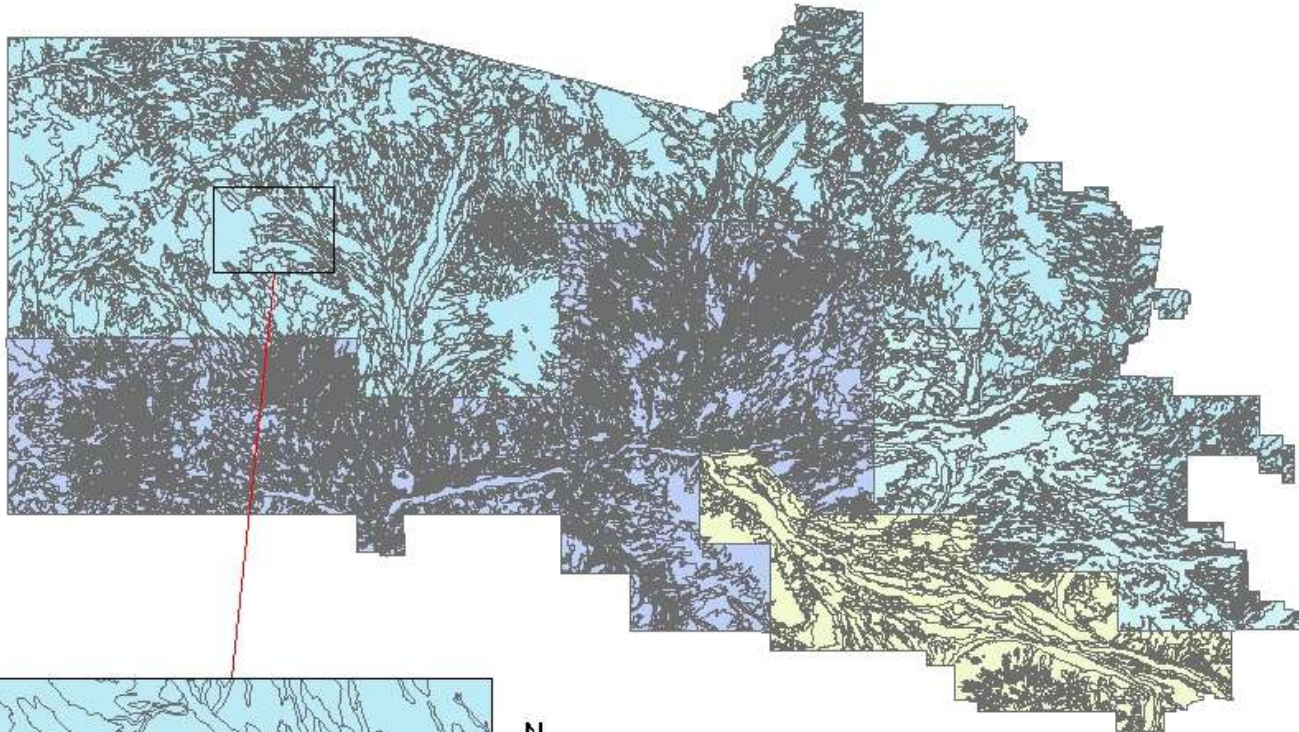
The next step is to query the database.





To query the database, logical expressions that impose limits or conditions on the database search are defined. These logical expressions specify which geographical objects are to be included in the analysis and/or how that data is to be analyzed.

Some of the queries performed are:

- Name the soils whose slope gradient was greater than 40%?
- What is the extent of soil types in Phoenix region? Values in Sq Kms.
- In a buffer zone of 1-mile radius around the city of Phoenix what are the various soils found?
- What are the various soils textures found in the region of Zacatacus in Mexico?
- Are any definite interesting patterns observed in the data for the regions of Mexico and Arizona?

Soils Boundary



-  Aguilá-Carefree Area, Parts of Maricopa and Pinal Counties
-  Maricopa County, Arizona, Central Part
-  Eastern Maricopa and Northern Pinal Counties Area, Arizona
-  Gila River Indian Reservation, Arizona, Parts of Maricopa and Pinal Counties

Crops Model

Dr. Jason Kaye and his students developed a simple production model for crops as described below.

Choose a time step Δt (e.g., one week or one month)

Let Soil Moisture = SM

$SM(t + \Delta t) = SM(t) + (\text{rainfall} + \text{irrigation} - PE) \Delta t$; (PE is Potential Evaporation).

If $SM(t + \Delta t) > FC$, $SM(t + \Delta t) = FC$ (FC is Field Capacity)

Keep a running tally of average SM ($\langle SM \rangle$) over 120-day (or given time period) growing period.

If SM from 0 days to 30 days is below some critical value (at Wilting Point -WP) then the *crop is killed*.

If rainfall from 100-140 days is $>$ some value, *the harvest rots*.

OTHERWISE ($Y = \text{Yield}$)

If $\langle SM \rangle > T$, $Y = Y_{\max}$

If $\langle SM \rangle \leq WP$, $Y = 0$

Otherwise, $Y = Y_{\max} * (\langle SM \rangle - WP) / (FC - WP)$

Logistic Model

Let Soil Moisture = s

Rainfall = r , Irrigation = i and Evaporation = e

We have the rate of change of s as,

$$s(t + \Delta t) - s(t)$$

Let, in time dt ,

$$\text{rainfall} = r s(t) dt$$

$$\text{irrigation} = i s(t) dt$$

$$\text{evaporation} = e s(t) dt$$

The change of s in time dt depends on rainfall, irrigation and evaporation. So we have,

$$s(t + \Delta t) - s(t) = r s(t) \Delta t + i s(t) \Delta t - e s(t) \Delta t$$

Continued..

$$s(t + dt) - s(t) = r s(t) dt + i s(t) dt - e s(t) dt$$

Substituting $r = n - i + e$ we have

$$s(t + dt) - s(t) = s(t) dt n$$

$$\frac{s(t + dt) - s(t)}{dt} = s(t) n$$

Applying Limits $dt \rightarrow 0$ we get,

$$\frac{d}{dt} s(t) = s(t) n$$

$$\frac{\frac{d}{dt} s(t)}{s(t)} = n$$

Exponential Model

Integrating on both sides we get,

$$\int \frac{1}{s} ds = \int n dt + C$$

$$\ln(s) = n t + C$$

The solution yields an exponential function, where e^C is a constant = s_0 .

$$s = e^{nt} e^C$$

$$s = s_0 e^{nt}$$

This is an *exponential model*. While soil moisture may manifest such increase of moisture content patterns during periods of short duration, it is clear that there must be factors which attenuate increase in the long run.

View

Logistic Model

Verhulst-Pearl Logistic Equation

One model that takes these factors into account is the Verhulst-Pearl logistic equation, $dN / dt = rN (1 - N / K)$.

Since the resources for moisture are generally limited, it is reasonable to assume that as moisture content in the soil increases and it approaches the carrying capacity which is in our case the field capacity K , of its environment, the rate of rainfall reduces, irrigation is not continued or irrigation rate is gradually reduced, and the evaporation rate begins to increase.

$$r = r_0 - k_r s$$

$$i = i_0 - k_i s$$

$$e = e_0 + k_e s$$

Continued..

In other words, the rainfall rate, irrigation rate and evaporation rates can be interpreted as linearly related to the amount of soil moisture. s will stabilize, or reach a fixed point, if

$$r + i = e$$

Or,

$$r_0 - k_r s + i_0 - k_i s = e_0 + k_e s$$

Solving for s , we get a carrying capacity K

$$K = \frac{r_0 + i_0 - e_0}{k_i + k_r + k_e}$$

Let $c = r_0 + i_0 - e_0$. Then,

$$k_i + k_r + k_e = \frac{c}{K}$$

Continued..

$$\frac{d}{dt} s(t) = s(t) n$$

Substituting $n = r + i - e$ we get,

$$\frac{d}{dt} s(t) = s(t) (r + i - e)$$

$$\frac{d}{dt} s(t) = s(t) (r_0 - k_r s + i_0 - k_i s - e_0 - k_e s)$$

$$\frac{d}{dt} s(t) = s(t) (r_0 + i_0 - e_0 - s(t) (k_r + k_i - k_e))$$

From earlier calculation we have $k_i + k_r + k_e = \frac{c}{K}$ and $c = r_0 + i_0 - e_0$.

$$\frac{d}{dt} s(t) = s(t) \left(c - \frac{s c}{K} \right)$$

The Logistic Model

Re-arranging the above equation we get,

$$\frac{d}{dt} s(t) = s(t) c \left(1 - \frac{s}{K} \right)$$

Where s is Soil Moisture and K is the Field Capacity. Thus, the net rate of growth in the logistic equation is continually changing. If s is small relative to its carrying capacity, K , the rate will be near to the constant rate, c , of the exponential model. As s nears K , the rate will shrink toward 0. Theoretically, when s reaches K a situation of equilibrium will be reached and the moisture content will be stable. If s were to somehow exceed K , the rate would become negative and the moisture would decrease toward the carrying capacity.

[View](#)

[Exponential Model](#)

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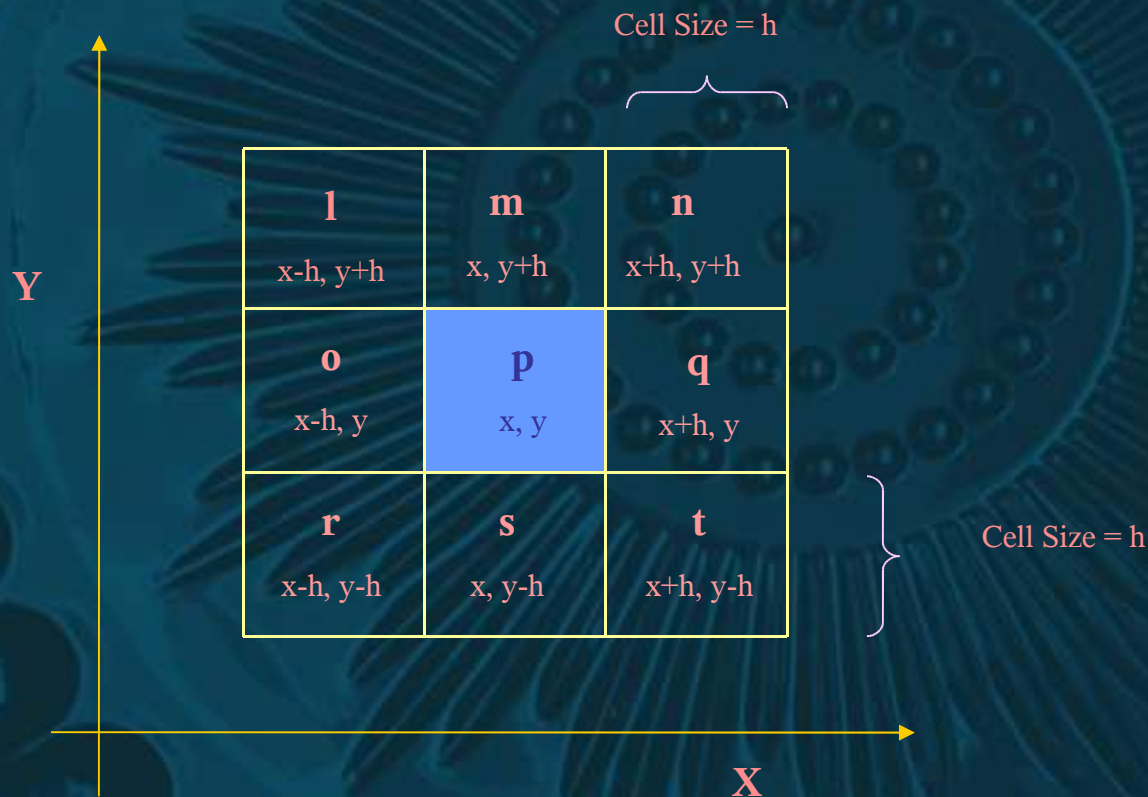
Model of the Pre-historic Canals Systems for Irrigation.

Steps for Developing a Geographical Model of Slope

- Step 1: Problem Statement
 - Develop a geographic model depicting the regions of pre-historic canals in Phoenix Basin to analyze the irrigation system.
 - Understand the slope and aspect ratio to determine how the ‘Hohokam’ people learned to control floods, irrigate their lands, grow crops etc.
 - Study the relation between the two cultures and find out if the Hohokam were originally people from Mexico.
- Step 2: Problem Breakdown
 - Develop a basic phoenix map showing the pre-historic canals.
 - Determine the various statistics that are required for analyzing the canals.
 - Project these statistics on the map.
 - Develop and query similar regions in Mexico.

Step 3

- Step 3: Exploring Input Datasets
 - Slope Analysis
 - Taylor Series Expansion



$$\sqrt{\left(\frac{dz}{dx}\right)^2 + \left(\frac{dz}{dy}\right)^2}$$

Taylor Series

$$f(x+h, y+k) = f(x, y) + \left(h \frac{\partial f}{\partial x} + k \frac{\partial f}{\partial y} \right) + \frac{1}{2!} \left(h^2 \frac{\partial^2 f}{\partial x^2} + 2hk \frac{\partial^2 f}{\partial x \partial y} + k^2 \frac{\partial^2 f}{\partial y^2} \right) + \dots$$
$$= \sum_{p=0}^{N-1} \frac{1}{p!} \left(h \frac{\partial}{\partial x} + k \frac{\partial}{\partial y} \right)^p f(x, y) + R_N$$

$$f(x+h, y) = f(x, y) + h \left(\frac{\partial}{\partial x} f \right) + \frac{1}{2} h^2 \left(\frac{\partial}{\partial x} f \right)^2 + O(h)^3$$

1

$$f(x-h, y) = f(x, y) - h \left(\frac{\partial}{\partial x} f \right) + \frac{1}{2} h^2 \left(\frac{\partial}{\partial x} f \right)^2 + O(h)^3$$

2

$$f(x, y+h) = f(x, y) + h \left(\frac{\partial}{\partial y} f \right) + \frac{1}{2} h^2 \left(\frac{\partial}{\partial y} f \right)^2 + O(h)^3$$

3

$$f(x, y-h) = f(x, y) - h \left(\frac{\partial}{\partial y} f \right) + \frac{1}{2} h^2 \left(\frac{\partial}{\partial y} f \right)^2 + O(h)^3$$

4

Continued..

$$f(x+h, y+h) - f(x, y) = h \left(\frac{\partial f}{\partial x} + \frac{\partial f}{\partial y} \right) + \frac{1}{2} h^2 \left(\frac{\partial^2 f}{\partial x^2} + 2 \frac{\partial^2 f}{\partial x \partial y} + \frac{\partial^2 f}{\partial y^2} \right) + O(h^3) \quad 5$$

$$f(x-h, y-h) - f(x, y) = h \left(-\frac{\partial f}{\partial x} - \frac{\partial f}{\partial y} \right) + \frac{1}{2} h^2 \left(\frac{\partial^2 f}{\partial x^2} + 2 \frac{\partial^2 f}{\partial x \partial y} + \frac{\partial^2 f}{\partial y^2} \right) + O(h^3) \quad 6$$

$$f(x+h, y-h) - f(x, y) = h \left(\frac{\partial f}{\partial x} - \frac{\partial f}{\partial y} \right) + \frac{1}{2} h^2 \left(\frac{\partial^2 f}{\partial x^2} - 2 \frac{\partial^2 f}{\partial x \partial y} + \frac{\partial^2 f}{\partial y^2} \right) + O(h^3) \quad 7$$

$$f(x-h, y-h) - f(x, y) = h \left(-\frac{\partial f}{\partial x} + \frac{\partial f}{\partial y} \right) + \frac{1}{2} h^2 \left(\frac{\partial^2 f}{\partial x^2} - 2 \frac{\partial^2 f}{\partial x \partial y} + \frac{\partial^2 f}{\partial y^2} \right) + O(h^3) \quad 8$$

Subtracting equation 2 from equation 1, we get equation 9

$$f(x+h, y) - f(x-h, y) = 2h \left(\frac{\partial f}{\partial x} \right) + O(h^3)$$

$$\frac{\partial f}{\partial x} = \frac{1}{2h} \frac{f(x+h, y) - f(x-h, y)}{h} + O(h^2)$$

9

Continued..

Subtracting equation 4 from equation 3, we get equation 10

$$f(x, y+h) - f(x, y-h) \approx h \left(\frac{\partial}{\partial y} f \right)$$

$$\frac{\partial}{\partial y} f \approx \frac{1}{2} \frac{f(x, y+h) - f(x, y-h)}{h}$$

10

Subtracting equation 5 from equation 6, we get equation 11

$$f(x-h, y+h) - f(x-h, y-h) \approx h \left(\left(\frac{\partial}{\partial x} f \right) - \left(\frac{\partial}{\partial y} f \right) \right)$$

11

Subtracting equation 8 from equation 7, we get equation 12

$$f(x+h, y+h) - f(x-h, y+h) \approx h \left(\left(\frac{\partial}{\partial x} f \right) + \left(\frac{\partial}{\partial y} f \right) \right) \approx h \left(\frac{\partial}{\partial x} f \right) \left(\frac{\partial}{\partial y} f \right)$$

12

Adding equation 11 and equation 12, we get equation 13.

$$f(x-h, y+h) - f(x-h, y-h) - f(x+h, y+h) + f(x-h, y-h) =$$

$$4h \left(\frac{\partial}{\partial x} f \right) \left(1 - h \left(\frac{\partial}{\partial y} f \right) \right)$$

$$\frac{\partial}{\partial x} f \approx \frac{1}{4} \frac{f(x-h, y+h) - f(x-h, y-h) - f(x+h, y+h) + f(x-h, y-h)}{h}$$

13

Continued..

Subtracting equation 11 from equation 12, we get equation 14.

$$\begin{aligned} & f(x+h, y+h) - f(x-h, y+h) - f(x+h, y-h) + f(x-h, y-h) = \\ & 4h \left(\frac{\partial}{\partial y} f \right) \left(1 - h \left(\frac{\partial}{\partial x} f \right) \right) \\ \frac{\partial}{\partial y} f &= \frac{1}{4} \frac{f(x+h, y+h) - f(x-h, y+h) - f(x+h, y-h) + f(x-h, y-h)}{h} \end{aligned} \quad 14$$

Adding equation 9 and equation 13, we obtain equation 15 in terms of $\frac{\partial}{\partial x} f$

$$\begin{aligned} \frac{\partial}{\partial x} f &= \frac{1}{8} (f(x+h, y+h) - f(x-h, y+h) - f(x+h, y-h) + f(x-h, y-h) \\ &+ 2f(x+h, y) - 2f(x-h, y))/h \end{aligned} \quad 15$$

Adding equation 10 and equation 14, we get equation 16 in terms of $\frac{\partial}{\partial y} f$

$$\begin{aligned} 2 \left(\frac{\partial}{\partial y} f \right) &= \frac{1}{4} (-f(x+h, y+h) - f(x-h, y+h) - f(x+h, y-h) + f(x-h, y-h) \\ &+ 2f(x, y+h) - 2f(x, y-h))/h \end{aligned} \quad 16$$

Final Equations

Substituting the nodes values from a through i in equation 15, we get $\frac{\partial}{\partial x} f$ as,

$$\frac{\partial}{\partial x} f = \frac{(n + 2q + t) - (l + 2o + r)}{8h}$$

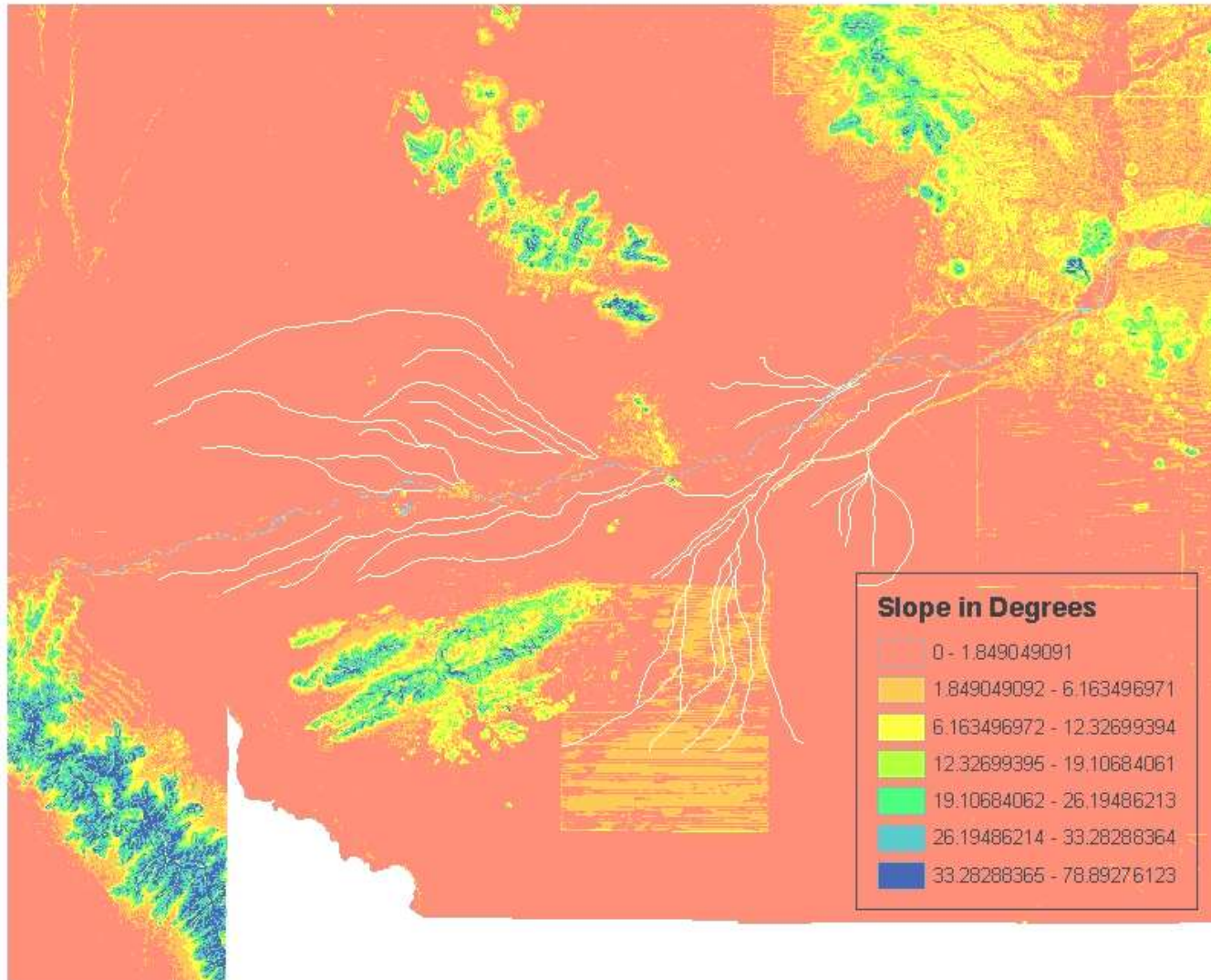
Substituting the nodes values from a through i in equation 16, we get $\frac{\partial}{\partial y} f$ as,

$$\frac{\partial}{\partial y} f = \frac{(l + 2m + n) - (r + 2s + t)}{8h}$$

Steps Continued..

- Step 4: Perform analysis
 - Spatial Analyst Extension in ArcMap software provides a wide variety of tools to serve this purpose. In this project I used the following tools:
 - Programming:** Visual Basic 6.0, SQL.
 - Databases:** MS Access Database, MS Excel.
 - Software Packages:** ArcGIS, ArcView, ArcInfo, ArcMap, ArcCatalog, ArcSDE, Adobe Photoshop, Microsoft office suite.
- Step 5: Verify the model's result
 - Perform Quality Control
- Step 6: Implement the result
 - The Result

Result



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Creating Maps

ArcMap™ software package provides two different ways to view a map.

3. Data view
4. Layout view

Steps in Map creation:

Step 1

The shape-files that are required to be projected in the form of a map are first brought together in a frame. The shape-file may include, images (Ex: Aerial image), polygons (Ex: Arizona Counties), points (Ex: Arizona Cities), or lines (Ex: Railways).

Steps 2 & 3

Step 2

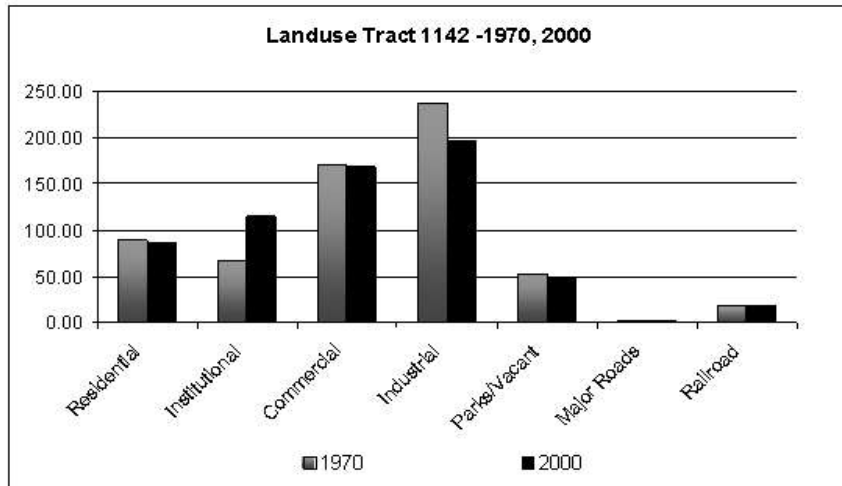
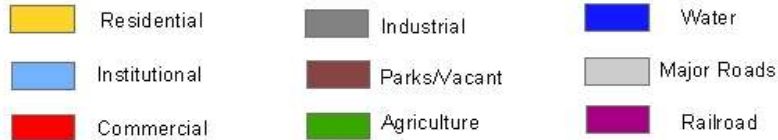
A layout is designed with required page set up where all the elements will be projected. Ex: 8 ½ X 11 inch, 1-inch margin, black border etc. On a layout one can add several features like data-frames, tables, images, objects and graphs. A layout can always be altered and made suitable for printing. The elements like legend, north arrow, title, description, labels are added to enhance the layouts. Map Locators can be added to zoom into specific sections and show it in a different view.

Step 3

This final map can now be printed, published and data can be super imposed for queries.

Result

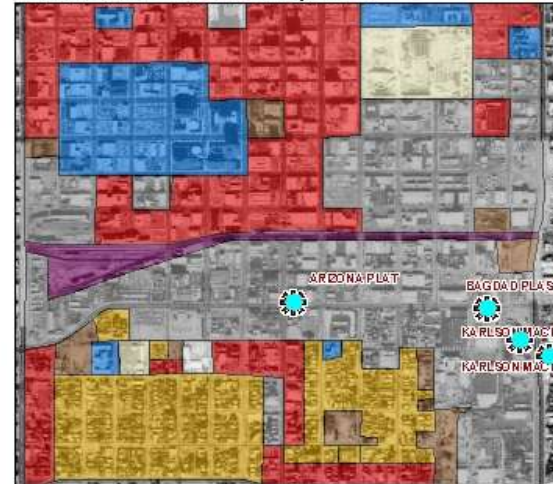
TRACT 1142 (T1N R3E S8)



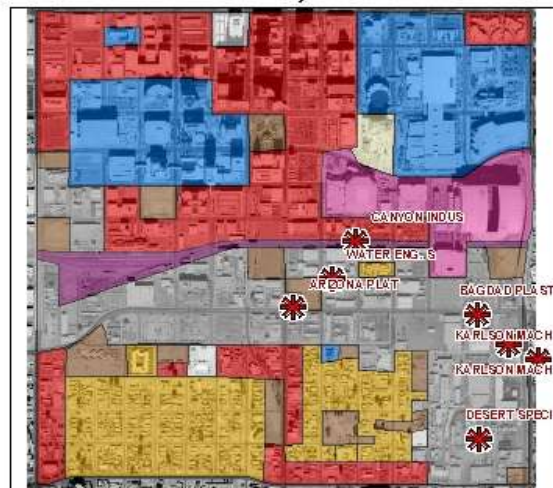
Year	White Not Latino		Latino		African American	
	Total	Percent	Total	Percent	Total	Percent
1970	3,384	31.90%	1,738	51.40%	401	11.80%
1980	3,133	21.10%	1,902	60.70%	463	14.80%
1990	4,182	30.90%	2,106	50.40%	641	15.30%
2000	3,940	24.40%	2,274	57.70%	579	14.70%

Data Source: Adapted from 1970-2000 US Census, ICPSR Terry Adams Dataset

Land use 1142 Tract, 1970



Land use 1142 Tract, 2000



Metadata

The following are a set of question the metadata must answer:

Identification information: What is the name of the data set? Who developed the data set? What geographic area does it cover? What themes of information does it include? How current are the data? Are there restrictions on accessing or using the data?

Data quality information: How good are the data? What is the positional and attribute accuracy? What data were used to create the data set, and what processes were applied to these sources?

Spatial data organization information: What spatial data model was used to encode the spatial data? How many spatial objects are there? Are methods other than coordinates, such as street addresses, used to encode locations?

Continued..

Spatial reference information: Are co-ordinate locations encoded using longitude and latitude? Is a map projection or grid system, such as the State Plane Coordinate System, used? What parameters should be used to convert the data to another coordinate system?

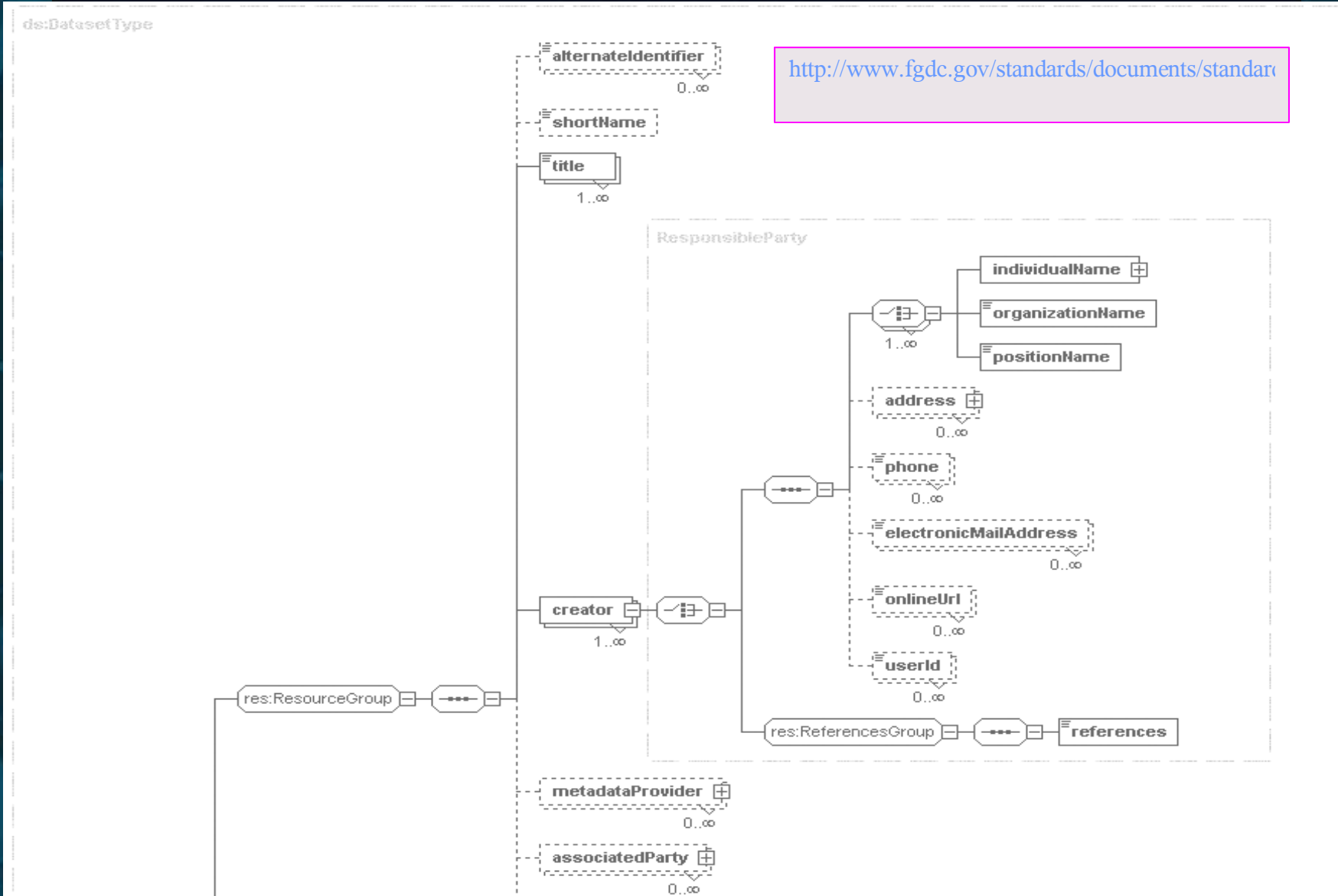
Entity and attribute information: What geographic information (roads, houses, elevation, temperature, etc.) is included? How is this information encoded? Were codes used? What do the codes mean?

Distribution information: From whom can I obtain the data? What formats are available? What media are available? Are the data available online? What is the price of the data?

Metadata reference information: When were the metadata compiled and by whom?

Metadata Design

<http://www.fgdc.gov/standards/documents/standards>



Future Work

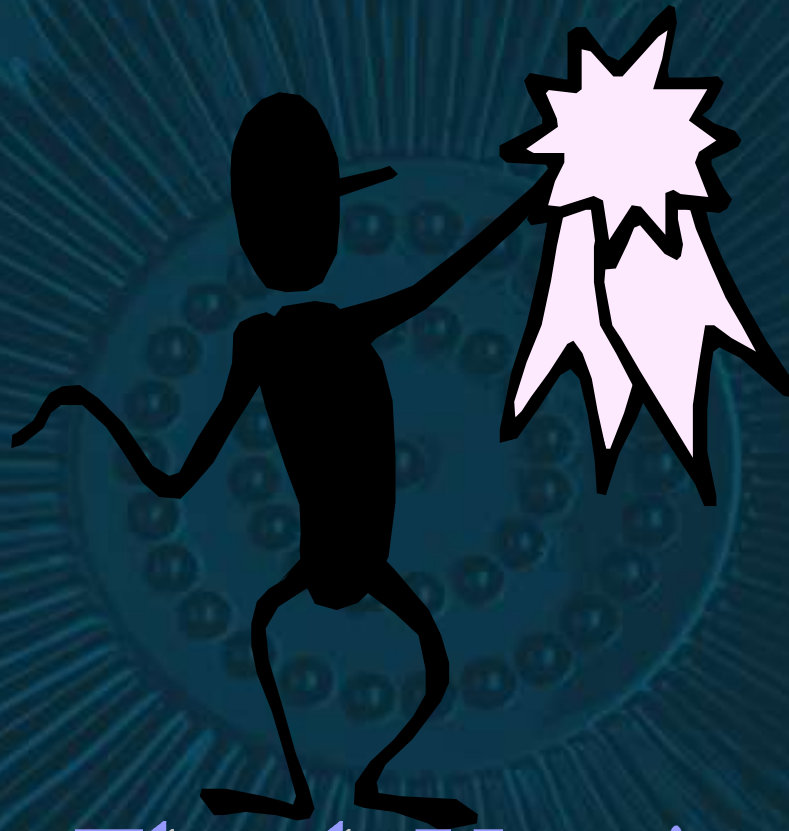
My future work will be concentrated in the area of Health Care where Geographic Information Systems can be used for the study and control of *infectious diseases*. For long, epidemiologists have traditionally used maps when analyzing associations between location, environment, and disease.

GIS is now being used in the surveillance and monitoring of vector-borne diseases, water-borne diseases, in environmental health, analysis of disease policy and planning, health situation in an area, generation and analysis of research hypotheses, identification of high-risk health groups, planning and programming of activities, and monitoring and evaluation of interventions.

GIS would enable researchers to locate high prevalence areas and populations at risk, identify areas in need of resources, and make decisions on resource allocation.

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Thank You !