

IDRISI GIS PROJECT - LOCATING SUITABLE WELL AREAS IN THE MANAGUA AQUIFER

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Introduction

This project concerns groundwater resources and uses data from the Managua aquifer in Nicaragua. It contains two parts – a first part mapping groundwater pollution sensitivity using map algebra and the DRASTIC assessment index (Aller et al., 1987). The second part is a localisation problem that uses Multi Criteria Evaluation (MCE) to find suitable sites for new groundwater wells (cf. Carver, 1992). A readymade data set over the Managua aquifer will be used as starting point (see McCarthy et al, 1997 for a description of the dataset and its quality). Additional data will be captured from Digital Chart of the World via www. The project is based on IDRISI, but can also be done using ArcView with the extension Spatial Analyst. The project should be presented as a scientific article.

Objective

The objective of the project is to identify new areas suitable for locating future well sites. Specifically groundwater vulnerability to pollution will be assessed, and decision support embedded in a geographical information system (GIS) will be used to identify suitable sites for new groundwater wells.

After having completed the project you should have acquired more knowledge about groundwater resources, and how to assess groundwater vulnerability to pollution. You shall also have acquired knowledge about techniques for multi criteria evaluation decision technique, and improved your skills in using GIS.

Background

Ground water vulnerability assessment

Groundwater is important for the water supply to many urban areas. Traditionally groundwater has been considered a low cost, safe source of water supply. Due to economic expansion, increasing demand and spatial growth of conflicting human activities, many groundwater resources (aquifers) are threatened. Urban areas in developing countries often find themselves in particularly exposed situation.

As not all groundwater is possible to protect in urban surroundings with rapid growth the concept of ground water vulnerability is attractive to decision makers, planners, and ground water managers. However, vulnerability is not an absolute, measurable property but rather a complex relative indicator. The International Association of Hydrogeologists (IAH, 1994) define vulnerability as "an intrinsic property of the ground water system that depends on the sensitivity of that system to human and/or natural impacts".

Several methods of ground water vulnerability assessment methods have been developed during the last ten years (see Scharp, 1999). One of the most widely used methods is DRASTIC (Aller et al, 1987).

DRASTIC parameter	weight
Depth to groundwater (m)	5
Recharge (mm/year)	4
Aquifer media	3
Soil media	2
Topography (slope in percent)	1
Impact of vadoze zone	5
Conductivity (transmissivity in m ² /s)	3

These parameters have different weights (w) according to their relative importance. In the methodology every parameter is assigned a rating (r) between 1 and 10 based on typical site characteristics. The ratings are retrieved from the DRASTIC tables (appendix 2). The final DRASTIC index is presented as a lumped index indicating the qualitative, relative pollution potential

$$D_w D_r + R_w R_r + \dots = \text{pollution potential.}$$

Spatial decision making

A decision is a choice between alternatives. For natural resources decision, GIS can be a powerful tool base for evaluation of choice alternatives based on spatially related criteria. A variety of analytical techniques have been developed to help decision makers solve location problems with multiple criteria. Embedded in a GIS such a tool is the base of a Spatial Decision Support Systems (SDSS). IDRISI has incorporated multi criteria evaluation (MCE) and multi objective land evaluation in a decision support module (Eastman et al., 1993; Eastman, 1997) that you will use for locating suitable sites new wells in the Managua aquifer. To learn more about MCE and spatial decision making please read the paper "Modelling in GIS".

Managua and its aquifer

The capital of Nicaragua, Managua, is situated next to a large aquifer, which is used for the city's water supply (Scharp, 1999). The city of Managua is rapidly expanding and this threatens both the quantity and quality of the Managua aquifer. The quantity problem has led to overexploitation of ground water in the vicinity of the city, and subsequently to quality problems because of induced infiltration from the nearby, and strongly polluted, lake Managua. This problem is now managed by seeking new well sites in the aquifer localised further away from the city.

Apart from being connected to the overexploitation, the quality is also threatened by different activities related to the expanding city (*ibid.*). Intensified agriculture, non-point sources of metals from e.g. illegal dumping sites and petro-chemical products are increasingly entering the area; refineries are established, as are gas-stations. The road system and its traffic is also growing steadily.

Instructions for locating suitable well areas in the Managua aquifer

Part I Mapping groundwater pollution potential

Start by copying the directories and files under geoserver\e\GIS MN2 vt99\managua\ to the local hard disk. Set the path under <ENVIRONMENT> to the directory that now holds the data. Have a look at the various images that are available to familiarise yourself with the dataset.

The first step necessarily is to create the basic maps, which include:

Layer	Creation
Digital elevation model	Existing (dem) – interpolated from digitised contour lines of 100 meter interval from a topographic map in the scale 1: 50 000.
Phreatic level (ground water table)	Digitized contour lines of the phreatic level are in the directory PHREATIC . The source map is a 1:50 000 scale hydrogeological map. You have to copy those files to your main directory, and then create an image of the water table with full areal coverage using these lines. To create the map of Phreatic level you first have to create an empty image by using <INITIAL>, use any existing image (e.g. geology) to set the co-ordinate system, set the file and data type to be integer binary. Then you have to use <LINERAS> to put the digitised vectors on to the map. Finally use <INTERCON> to calculate the phreatic level in every point of the map.
Precipitation	Digitised points with values of annual average precipitation are in the vector file prec , you can either use interpolation (<INTERPOL>) or thiessen polygons (<THIESSSEN>) to create an image of precipitation. Iterate the interpolation by using different parametesiations.
Actual evapotranspiration	Net recharge must be calculated as "precipitation - actual evapotranspiration". Hence you must estimate actual evapotranspiration somehow. Factors that influence this include temperature, vegetation density and infiltration capacity. Vegetation density you can calculate from the satellite image data (see separate paper on "Modelling with GIS"). You can assume the temperature to be 29 degrees Celsius in Managua (the same the whole year round).
Geology	Existing (geology). Digitised from a geological map in the scale 1: 50 000.
Soil	Existing as a DRASTIC index file (soil).
Impermeable layer underlying the aquifer	Existing (imper). Interpolated in segments from contour lines digitised from a hydrogeological map in the scale 1: 50 000.
Transmissivity	Existing (trans). Interpolated contour lines digitised from a hydrogeological map in the scale 1: 50 000.
Aquifer extension	Existing (mask). Digitised from a geological map in the scale 1: 50 000.

Once you have created all the input layers you must combine them with map algebra or reclassify them in order to create the DRASTIC index maps.

Index map	Creation
Depth	Calculate as "DEM – Phreatic"
Recharge	Calculate as "Precipitation – Actual evapotranspiration"
Aquifer media	Reclass of geology
Soil	Existing (soil)
Topography	Calculate from DEM
Impact of	Existing (vadoze)
Vadoze zone	
Conductivity	Calculate as "Transmissivity/aquifer thickness"

Hints and comments If you get unrealistic values, like negative numbers for depth to groundwater (which means that you should have a lake), you must change those values to their nearest logical value (i.e. a positive value in the example of depth to groundwater). The maps soil and vadoze are already indexed according to the DRASTIC system. They were done by domain experts in Nicaragua based on manual interpretations of various maps. The maps of dem, impermeable layer underlying the aquifer and transmissivity were done in a similar manner as the map of phreatic layer. However, as the interpolation in IDRISI is not very good, for more complicated maps those were done using another software (GRASS).

As DRASTIC in principle is an expert system, you must look in the tables (appendix 2) for the rating of each factor and <RECLASS> the index maps accordingly. Then combine all the maps to derive the final DRASTIC value. Note that DRASTIC uses the same algorithmic principle as MCE (which you must use later in the project). It is thus possible to use the <MCE> module to combine the factors in order to derive the DRASTIC index.

Part II – MCE for identifying suitable well locations

Many factors are important for localisation of a new well. Obviously the DRASTIC index is a good factor for determining the risk of the aquifer (and its wells) being polluted. But as important is of course the transmissivity of the well site, and conflicting activities – like agriculture, industrial activity, traffic systems etc. From an economic perspective the distance from the well to the sites of water demand is also important.

Multi criteria evaluation (MCE) and multi objective land allocation (MOLA) are decision support tools incorporated in IDRISI that can be used to solve spatially related problems. In the project we will only use multi criteria evaluation for identifying suitable well sites. A further step could have been to use MCE to also identify suitable areas for other activities (agriculture, industry, urban expansion) and then use MOLA to allocate land between those conflicting uses. However, that is beyond the scope of the project.

Criteria can be of two types: constraints and factors. Constraints are Boolean, and serve to exclude or open certain areas for considerations. Factors are continuous (ratings of 0 to 255 in the MCE module in IDRISI) and serve to enhance or diminish the suitability of the land for a particular application depending on the magnitude of the variable in question. In other nomenclature factors are equivalent to decision variables or structural variables.

Criteria for localisation of wells

Constraints

Within the aquifer	Outside the aquifer water is not sufficient
Not in direct contact with pollution sources	Roads, built up areas and industrial sites must be avoided

Factors

Transmissivity	High transmissivity is suitable
DRASTIC index	Low DRASTIC index is suitable
Depth to groundwater	Low depth is suitable (cheaper to drill and pump)
Proximity to pollution sources	Large distance to pollution is suitable
Proximity to consumers	Closeness to consumers is suitable

The next step is to construct the constraints and factors that we are going to use for identifying suitable well sites. As noted above Constraints are Boolean, with areas open for consideration having the value 1 and excluded area the value 0. Factors can have a maximum value of 255, and the range of values can either represent just a relative ratio, or a physically interpretable range. A higher value is more suitable than a lower. In general the way to set the rating is to use the command <STRETCH> or <FUZZY> in order to set all pixels to values between 0 and 255. You can also use more physical values for rating the factors, however you are confined to use the range 0 to 255. Both constraints and factors must be Byte Binary – which is why the values can not be outside the range 0 to 255. You also have to capture some data from Digital Chart of the World (see appendix 1).

Constraints	
Within the aquifer	The mask is already there, so this is OK
Pollution sources	Create a Boolean map with roads, industries and the built up areas as zero. To find the roads and built up areas you have to import them from DCW (see appendix 1). Industries are in the file industry.vec , and must be rasterised using <POINTRAS>.
Factors	
Transmissivity	Either use <STRETCH> or <FUZZY> to put transmissivity in a relative range 0 to 255, or use <SCALAR> and/or <CONVERT> to create a more physical interpretation and a file in the byte binary format.
DRASTIC	See transmissivity
Depth to groundwater	See transmissivity
Proximity to pollution sources	First you must do a <DISTANCE> analyses using roads, industries and built up areas as reference. After that the same steps as for Transmissivity have to be applied.
Proximity to consumers	This is done in a similar manner as Proximity to pollution sources, however note that you have to invert the scoring, so that short distances get the highest rating (use <INITIAL> to create a file with the highest rating as initial value, subtract your factor file

	from this file – and <i>voila</i>).
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Before doing the actual MCE you must assign weights to your factors. This is the essential step in the decision making process. To compare the relative importance of the factors, construct a pairwise comparison matrix for all the factors. The relative importance should be given values from 1/9 to 9/1.

Example of matrix for relative importance of pairwise factors.

	Transmiss.	DRASTIC	Grw depth	Proximity to Pollution	Proximity to consumers
Transmiss	1				
DRASTIC	2	1			
Grw depth	1/3	x	1		
Proximity to Pollution	1/y	z	x'	1	
Proximity to consumers	y'	z'	xx'	yy'	1

After having discussed and derived the relative importance, run the module <WEIGHT>. You will be presented with best fit weights and a judgement of the consistency of the weights. Repeat the pairwise weighing iteratively until you get a consistent set of weights. Note those weights and save the pairwise comparison file (*.pcf). Run the <MCE> module.

The result of running <MCE> is a suitability map. Use this map to derive the best areas for new wells. There are several ways to go, you can for instance use <RANK> to find the areas with the highest ratings. You can also aggregate areas with a suitability rating above a certain threshold by using <RECLASS> and <GROUP>, and then select areas that have a certain size (protected inner well area). A better solution is to combine the two suggestions.

When you are satisfied with your images (and the legends – which can be changed by pressing shift and the right mouse button pointing at the legend category to be changed), dump them as bitmaps using the Composer. Run <HISTO> if you want a statistical description in your report.

Hint to capture screen parts The program "Snagit" is a nice tool for capturing any part of the screen and convert it into a bitmap (for instance maps or charts). You can download Snagit from the internet –.

Part III - Report writing

The project must be reported in a written paper. Use times roman, size 12, with double spacing and margins on all sides of 2.5 cm. The paper should contain the following:

Title
 Abstract
 Key words
 Introduction
 Why did you start?

Material and methods	How did you do it?
Results	What answer did you get?
Discussion	What does it mean?
References	Written as in this instruction!

Your report shall contain (at least) two maps, one showing the DRASTIC index and one showing your identified well sites.

References

Aller, L., T. Bennet, J.H. Lehr and R.J. Petty, 1989. DRASTIC: a standardised system for evaluating groundwater pollution potential using hydrogeological settings. U.S: Environmental Protection Agency, Oklahoma.

Carver, S.J., 1991. Integrating multi-criteria evaluation with geographical information systems. *Int. J. Geographical Information Systems*, 5: 321-339.

IAH (International Association of Hydrogeologists), 1994. Guidebook on mapping ground water vulnerability, ed J. Vrba and A. Zaorozec, IAH series, vol. 16 Verlag Heinz Heise, Hannover.

McCarthy, J., M. Hessling and T. Gumbricht, 1997. Modelling the Managua aquifer. 1: data creation in a developing region. In: H. Hauska (Ed), *Proceedings ScanGIS'97 The 6th Scandinavian research conference on Geographical Information Systems 1st 3rd June 1997* Stockholm, pp 201-208.

Scharp, C., 1999. Strategic groundwater protection - a systematic approach. Royal Institute of Technology, Division of Land and Water Resources. TRITA-AMI, PhD 1028, Thesis

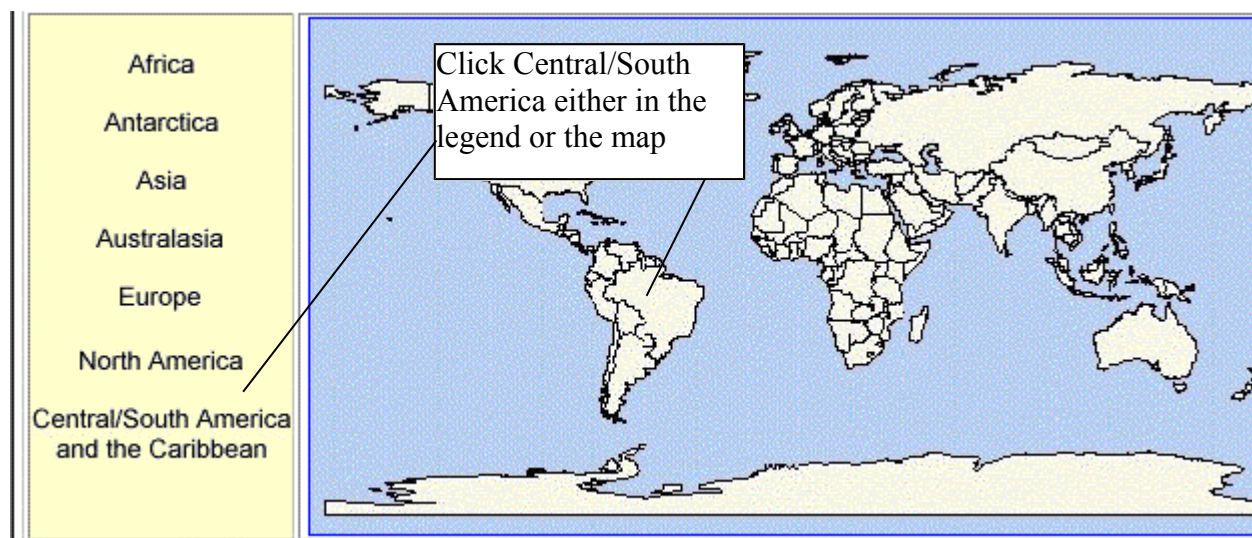
Appendix 1

Capture data from Digital Chart of the World (DCW) from the internet

DCW is a set of maps with global coverage, and is originally a product from ESRI (Environmental System Research Institute, Inc.; that is the company that also produces Arc Info and Arc View). DCW exists in many versions, and we will use the one available at Penn State University. Their version exist as the Arc Info export format *.e00 that can be used by ArcView and subsequently by IDRISI. However there are many steps before we get a useful map. To learn more about DCW look at www.maproom.psu.edu/dcw/

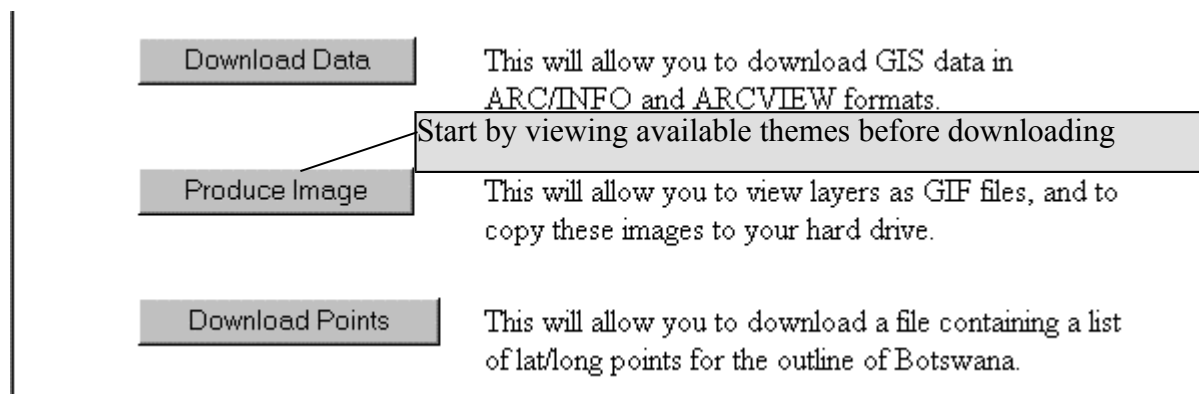
When you have learnt about DCW, download the maps of your selected study area.

Use Internet Explorer or Netscape navigator to go to www.maproom.psu.edu/dcw/, from the world map select the Central/South America tile to work with and then Nicaragua from the list that appears to the right.



Digital Chart of the World

To see what data is available you can choose the option [Produce Image] and select the themes that you think are relevant. Try to figure what maps are important for your project.



DCW download manager

If you feel uncertain about what maps to use the following are suggested as a starting point:

Name	Content	Type
dnnet	Drainage	Coverage (arcs and polygons)
ponet	Political/ocean boundary	Coverage (arcs and polygons)
lcpoly	Land cover	Polygon
rdline	Roads	Arcs
pppoly	Populated areas (i.e. cities)	Polygon

Select the layers you want to download and continue. In the DCW download manager do select [Data Compression Type] to be PC/NT and [Optional Arc View Projects] to be NONE. Then press [Compute Data]. Then just [Download Coverages]. If the downloading does not work (not uncommon) you must use a manual FTP program to download. Note the name and directory of the file that the Download Manager created for you. Use the NT explorer to locate and start the FTP program on your PC (normally that would be under the directory C:\ftp-protokoll or somewhere under program files (if you do not have a FTP program there is a shareware called eleetftp that you can download from www.shareware.com). To ftp your file with DCW from PSU use the following declarations for connecting:

URL	ftp://maproom.psu.edu/dcw_data/xx (where xx is a number given to your file by the DCW download manager)
Host name	Ortelius.maproom.psu.edu
Host type	Automatic detection
User-ID	Anonymous
Password	Anonymous

Put the file in your working directory.

The DCW files that you got from PSU are zipped, so you need to unzip them. There are several programs available for this, including sharewares.

The unzipped files all have the extension *.e00, this is the export format of ArcInfo, and it can be imported to Arc View. However the import program is a stand alone program. Use the NT explorer to find the program called Import71 which is located under C:\ESRI\AV_GIS30\ARCVIEW\BIN32. You have to import all the maps individually, and you have to put each map in its own directory.

Now it is time to start ArcView. If you do not have an ArcView icon on your desktop it is recommended that you create one. Use NT explorer to locate the Arc View program, which you find under C:\ESRI\AV_GIS30\ARCVIEW\BIN32. Create a short cut to the program and drop it on your desk top. Start ArcView.

The files that you created with Import71 are ArcInfo coverages, that means that they are not in the standard Arc View format called Shape. To be able to import the files into IDRISI we have to convert the files to the Shape format.

Open an empty view in your project and use the Add tool to pick up the DCW data layers that you imported. When you get the add menu, do select the feature you want to add with one click on the mouse (do not double click), and do put the mouse marker over the graphics of the file not over the text! The features shadowed by a yellow portfolio are coverages (see page

49 in the ArcView manual). This means that they contain more than one feature. If you have clicked once on the graphics for a coverage you should get a subset list of available features to add – this is most important for dnnet, but also concerns other coverages. If you double click a coverage you will only get the default feature. To learn more about data formats that can be used in Arc View look in the manual on pages 48 - 49.

You have to pick up the following themes, and for all of them you have to use **Convert To Shapefile** under **Theme** in the menu to save them as Shape files.

Content	Add and save as
Drainage	Polygons
Drainage	Arcs
Political/ocean boundary	Polygon
Political/ocean boundary	Arcs
Land Cover	Polygon
Roads	Arcs
Population (areas)	Polygons

Now you can return to IDRISI and use the command <SHAPEIDR>, found under the Import/Export menu, which in turn is found under File in the main menu. Once imported you can display the DCW data as vectors in IDRISI. To use them in the project you have to rasterise them, simply use <LINERAS> or <POLYRAS>. If it all worked out you should be able to add roads, lakes, rivers, and built up areas. By adding this data you can also do a better layout for inclusion the report.