GROUND WATER VULNERABILITY ASSESSMENT

SNAKE RIVER PLAIN, SOUTHERN IDAHO

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DISCLAIMER

The vulnerability maps described in this document highlight areas sensitive to ground water contamination in a generalized way. These maps do not show areas that will be contaminated, or areas that cannot be contaminated. Likewise, these maps do not show if a particular area has already been contaminated. Whether the area will have ground water contamination depends upon the likelihood of contaminant release, the type of contaminants released, and the frequency of that release. These maps only consider the ability of water to move from the land surface to the water table and do not consider the individual characteristics of specific contaminants.

Users of these maps should keep in mind that a low vulnerability rating is not an open ticket for uncontrolled land-use practices. A low vulnerability rating merely suggests that there is a lower chance of ground water contamination than in areas of higher vulnerability. Just about any ground water resource can be contaminated if it is subjected to improper land use practices. Prudent ground water protection measures are always warranted under any circumstances.

Users of these maps should also keep in mind that these maps are not designed for use in site-specific applications such as whether to site a landfill in a particular location. For instance, there could be smaller areas of high vulnerability within low vulnerability areas and vice versa. The maps can be used as a first-cut approximation of the vulnerability of certain areas, but more in-depth studies must be performed for site-specific applications.

The maps described in this paper are the first attempt at mapping vulnerability of ground water resources to contamination for the Snake River Plain. These maps will most likely be updated in the future as the techniques and information are refined.

EXECUTIVE SUMMARY

The Idaho Ground Water Vulnerability Project was initiated by the Idaho Department of Health and Welfare to rate areas within the state for their relative ground water pollution potential. The Idaho Department of Health and Welfare (IDHW) combined their efforts and expertise with the Idaho Department of Water Resources (IDWR), the U.S. Geological Survey (USGS) and the U.S.D.A. Soil Conservation Service (SCS) to develop the vulnerability maps.

The Project utilized a modified form of DRASTIC (Aller et. al., 1985) which was developed by the National Water Well Association under contract to the U.S. Environmental Protection Agency. The DRASTIC model evaluates the ground water pollution potential of a given hydrogeologic setting based on a set of defined characteristics, along with ratings or "weights" assigned to those characteristics. This project utilized three layers which resemble those used by DRASTIC (depth-to-water, soils, and recharge), but differ greatly from DRASTIC in that they used different sources of information, a finer scale, and a different point rating scheme. The Project used a Geographic Information System (GIS), which gives the ability for enhanced data analysis and integration capabilities over the standard cartographic techniques used by DRASTIC.

1) Description of Data Layers

a) Depth-to-water Layer

The depth-to-water layer (Figure 2) was developed by the U.S. Geological Survey (Maupin, in press-a; Maupin, in press-b). Depth-to-water is important for susceptibility assessment because areas where the ground water is close to the surface typically have a higher probability of ground water pollution than areas where ground water is quite deep. A computer program (Universal Kriging) was used to generate a surface representing first-encountered ground water below land surface from measured water levels. The depth-to-water values were generated by subtracting land-surface altitudes from the KRIGED water-level surface using a simple FORTRAN program. The depth-to-water map was then contoured and broken into categories, with each category rated on a scale of 1 to 50 points to reflect its relative significance to ground water vulnerability. The following ratings were used:

Depth-to-water Ranges	Rating (points)
1 to 25 feet	50
26 to 50 feet	35
51 to 100 feet	20
101 to 250 feet	10
> 250 feet	1

b) Recharge Layer

The "recharge" component of the Ground Water Vulnerability Model was developed by the Idaho Department of Water Resources. This layer represents water that penetrates the ground surface and percolates to the water table, potentially carrying contaminants with it (Figure 4).

The "recharge" map combined three data sets or layers that indicate types of land cover. The first layer outlines irrigated and dry cropland. The second layer differentiates between sprinkler- and gravity-fed irrigation delivery systems. The third layer subdivides land cover types into five categories representing rangelands, agricultural lands, forests, lava flows, and riparian areas. Each resulting recharge class was given the following point rating to be used in determining relative vulnerability:

Recharge Classes	Rating (points)
Gravity-fed irrigated land	50
Riparian areas	50
Sprinkler-fed irrigated land	40
Forests	30
Dryland agriculture	20
Rangeland	20
Bare rock (lava flows)	10
Urban areas	No rating
Surface water	No rating

c) Soils Layer

The soils layer (Figure 5) incorporated the State Soil Geographic Database (STATSGO) and SOILS-5 databases developed by the SCS. Four soil-landscape characteristics were chosen to be included in the soils layer. These characteristics are: 1) permeability of the most restrictive layer; 2) depth-to-water table within the soil horizon; 3) depth to bedrock; and 4) flooding frequency. Each characteristic was rated to reflect its relative significance to ground water susceptibility. The ranges of possible scores for the soils layer are as follows:

Soil Characteristics	Rating (points)
1) permeability	2 to 20
2) depth to bedrock	1 to 10
3) depth to water-table	0 or 8
4) flooding frequency	0 to 5
Total	2 to 43

The score for each soil unit was then multiplied by three to determine the final soils susceptibility rating. This was done because the soils layer incorporates more than one criteria relevant to ground water susceptibility assessment, and hence deserves more weighting than the other two layers.

2) Vulnerability Map

The Ground Water Vulnerability map (Figure 6) was generated by merging the three characteristics (depth-to-water, recharge, and soils) into one map using computer mapping (Geographic Information System) techniques. The point ratings from each layer were added to create a total vulnerability rating.

The final vulnerability map was broken into four categories of relative vulnerability; low, moderate, high, and very high. The division points for these categories were derived by graphing the relationship of total acres versus total vulnerability factor (Figure 7). The resulting distribution is 30% = low, 30% = moderate, 30% = high, and 10% = very high vulnerability (Figure 8). These divisions will be refined in the near future by comparing the vulnerability maps with ground water monitoring data, and then adjusting the divisions to correlate with the monitoring data in a statistically-valid fashion.

3) Uses of Vulnerability Maps

The vulnerability maps are designed to serve as a tool for prioritizing ground water management activities. Areas of higher vulnerability can be given higher priority for prudent ground water protection measures and study in order to assure that limited resources are effectively used in areas of greatest concern. Because of the scale of mapping that was incorporated in the development of these maps, they should be used for regional program planning purposes only, and should not be used for making site specific decisions. This is because there could be smaller areas of very high vulnerability within generalized areas of low vulnerability, and vice versa. Programs which can utilize vulnerability maps include leaking underground storage tanks (LUST), wellhead protection, ground water monitoring, public water supplies, agricultural chemicals, waste water management, best management practice (BMP) implementation and development, hazardous waste management, state and federal superfund programs, land use planning, State underground tank insurance agencies, and public information.

INTRODUCTION

The Idaho Ground Water Vulnerability Project was initiated by the Idaho Department of Health and Welfare to rate areas within the state for their ground water pollution potential. The goals of the Project are to: (1) assign priorities for development of ground water management and monitoring programs; (2) build public awareness of vulnerability of ground water to contamination; (3) assist in the development of regulatory programs; and (4) provide access to technical data through the use of a GIS (geographic information system). Programs which could utilize vulnerability maps include underground storage tanks, wellhead protection, ground water monitoring, public water supplies, agricultural chemicals, waste water management, best management practice (BMP) implementation and development, hazardous waste management, state and federal superfund programs, land use planning, State underground tank insurance agencies, and public information.

Making the Idaho Ground Water Vulnerability Project a reality required the effort of a number of agencies. The IDHW identified the program needs, but they did not have all the tools to make it work. The Idaho Department of Water Resources (IDWR), the U.S. Geological Survey (USGS) and the U.S.D.A. Soil Conservation Service (SCS) assisted in the development of the vulnerability maps by lending their expertise in their various fields of specialization. Mapping was originally performed on a pilot project basis for the Lake Walcott 1:100,000 scale quadrangle. Once that project was successfully completed in 1988, mapping was extended across the entire Snake River Plain and tributary valleys.

The term vulnerability is a combination of two concepts related to the assessment of ground water pollution potential; hydrogeologic susceptibility and contaminant loading potential. Hydrogeologic susceptibility includes the naturally-occurring factors related to the estimation of pollution potential such as depth-to-water, soils, vadose zone, or aquifer media. Contaminant loading potential includes man made sources of pollution such as underground petroleum storage tanks or feedlots. Contaminant loading potential is important for vulnerability assessment, because irrespective of susceptibility, ground water contamination cannot occur without contaminant loading. This study performs most of its ratings based on hydrogeologic susceptibility, but also incorporates information related to contaminant loading potential. Future work will address contaminant loading potential in greater detail.

1) Area of Study

This study developed digital maps in all or part of twenty (20) 1:100,000-scale quadrangles on the Snake River Plain and surrounding tributary valleys (Figure 1). The 20 quadrangles cover about 33,980 mi^2 and extend from the Idaho-Oregon border

Idaho Snake River Plain
Groundwater Vulnerability Study Area
100k Quads Affected

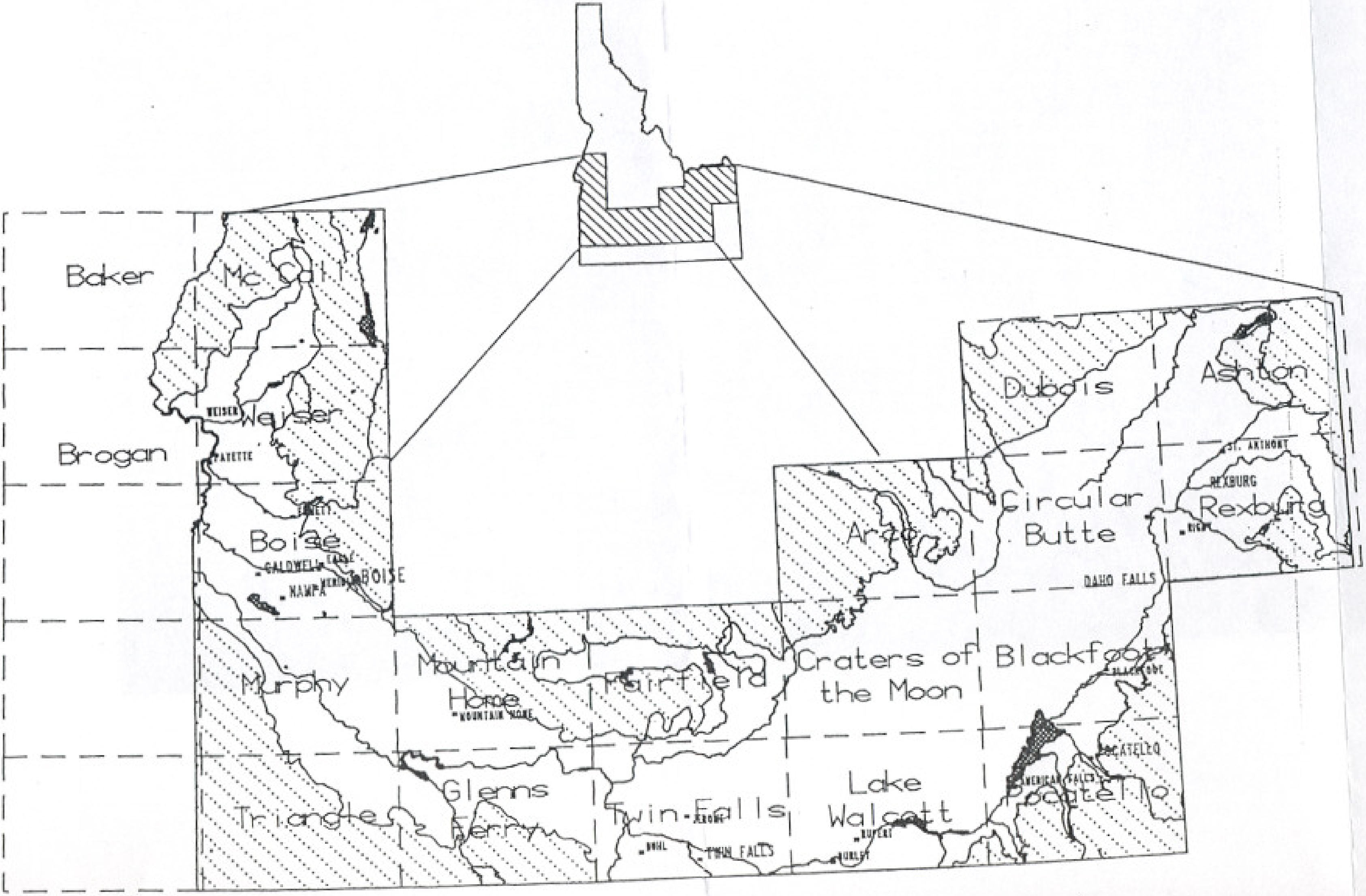


Figure 1: Location map of study area

eastward to the Idaho-Wyoming border. The Snake River Plain encompasses nearly 15,600 mi^2 of the total 33,980 mi^2 (Maupin, in press-a; Maupin, in press-b). The tributary valleys cover almost 3,700 mi^2 of the total 33,980 mi^2. Mountainous areas, for which no depth-to-water data were available, cover nearly 14,680 mi^2 of the total quad area. Included are all or parts of the Arco, Ashton, Blackfoot, Boise, Brogan, Circular Butte, Craters of the Moon, Dubois, Fairfield, Glenns Ferry, Lake Walcott, McCall, Mountain Home, Murphy, Pocatello, Rexburg, Triangle, Twin Falls, Vale, and Weiser quadrangles.

The Eastern Snake River Plain is a structural downwarp containing a complex of calderas with a great thickness of silicic volcanic rocks overlain by several thousand feet of Quaternary basalt flows and interbedded layers of gravel, sand, silt, and clay (Mabey, 1982). Occurrence of basalt flows decreases westwardly across the Eastern plain, with occurrence of alluvial deposits increasing. The Eastern plain is underlain by the Snake River Plain Aquifer (Lindholm, 1986; Lindholm & others, 1988). The Western Snake River Plain is generally considered to be a fault-bounded depression with normal faults forming major segments of both edges of the plain (Malde, 1965). Deep oil and geothermal wells drilled on the Western Snake River Plain revealed lacustrine sediments several hundred meters thick underlain by 1,000 to 2,000 meters of basalt flows with interbedded sediments (Mabey, 1982). The Western Snake River Plain is underlain by several aquifers under different depths and conditions. Ground water resources located under both the Eastern and Western Snake River Plain are a major source of water for agricultural, industrial, municipal, and domestic uses (Lindholm, 1986). Perched ground water zones occur locally throughout the both the Eastern and Western Snake River Plain.

Also mapped were tributary valleys to the Snake River Plain which were located within the quadrangle boundaries. The valleys are mostly underlain by alluvial sediments with some basalt flows, predominantly where the valleys meet the Snake River Plain (Maupin, in press-a; Maupin, in press-b). Ground water is mostly unconfined; some confining conditions exist where local clay lenses are present. Most water use is for domestic, stock, and irrigation purposes. Ground water in the tributary valleys generally flows down the valleys toward the Snake River Plain.

2) Use of Computers

An automated geographic information system (GIS) was utilized in the development of the ground water vulnerability maps because it is an efficient way to evaluate the relationships between various environmental, geological, and land use parameters. Not only is a GIS a useful tool for observing and analyzing the spacial relationships of data, but once the data layers are developed they can be used by a multitude of other programs for a variety of different applications, and can be readily adapted as more information becomes available.

The Idaho Ground Water Vulnerability Project used ARC/INFO[1] software for the development of the associated map coverages. ARC/INFO consists of two data bases that work together to keep track of, and analyze, spatially related data consisting of features (points, lines, or polygons). ARC is the graphics part of the system which draws features in their correct positions. INFO, the tabular data base, is the bookkeeping part of the system that consists of attributes such as well depth, water levels, soil information, irrigation practices, etc. ARC/INFO contains software capable of editing, plotting, estimating, and contouring.

Data falling into a specific category (such as soils or recharge) were built into a data "layer." Then, using GIS techniques, several layers were superimposed with the spatial and relational characteristics of each layer being combined. A composite map with final vulnerability ratings was generated utilizing information from each layer.

3) **Use of DRASTIC**

The Vulnerability Project developed a modified form of DRASTIC (Aller et. al., 1985) which was originally produced by the National Water Well Association under contract to the U.S. Environmental Protection Agency (EPA). The DRASTIC model evaluates the ground water pollution potential of a given hydrogeologic setting based on a set of defined characteristics, along with ratings or "weights" assigned to those characteristics. These ratings are based on the perceived contribution of a given characteristic to ground water vulnerability or pollution potential. DRASTIC is an acronym for the various criteria which the model incorporates. These are; depth-to-water (D), recharge (R), aquifer media (A), soils media (S), topography (T), impact of the vadose zone (I), and hydraulic conductivity of the aquifer (C).

This project utilized three layers which resemble those used by DRASTIC (depth-to-water, soils, and recharge), but differ greatly from DRASTIC in that they used different sources of information, a finer mapping scale, and a different point rating scheme. The soils layer had much more detailed, varied, and soils-specific data than in the original DRASTIC soils data layer. This was because the Idaho Project used the

[1] Use of brand names in this publication is for identification purposes only and does not constitute endorsement by the authors or their respective agencies.

STATSGO (State Soil Geographic Database) and SOILS-5 databases developed by the Soil Conservation Service. The Recharge layer varied significantly from DRASTIC because it incorporated irrigation practices as the largest contributor to recharge because of the typically low precipitation in the Snake River Plain. It too was developed at a much more detailed level than that used by DRASTIC. The depth-to-water layer is different from that used in DRASTIC because this project used water level information from over 1200 wells, and generated the layer using a statistical KRIGING package and computer contouring techniques. All three layers used different point rating systems, and were rated relative to each other differently than DRASTIC. This project also varied from DRASTIC in its use of a GIS, which allowed spacial analysis and advanced computer-aided mapping techniques during development of the vulnerability maps. DRASTIC was generated through standard cartographic techniques.

The Vulnerability Project did not develop layers for the vadose zone, aquifer media, hydraulic conductivity, and topography. The vadose zone was not developed because it was not cost effective to build that data layer using existing data sources. However, the vadose zone layer is believed to be a crucial layer in susceptibility assessment, and much emphasis will be focused on developing this layer in the future. The aquifer media and hydraulic conductivity layers were not developed because it was not cost effective to build the layers, and it was believed that available sources of information were not of high enough quality. The topography layer was not developed because data were not readily available to develop this layer in a cost effective manner, and because it was believed this layer is not as important in ground water susceptibility determination and hence received a lower priority for development. Depending on funding levels and available resources, all of these layers may be developed in the future.

DESCRIPTION OF DATA LAYERS

The following is an in-depth description of the depth-to-water, recharge, and soils data layers used by the Idaho Ground Water Vulnerability Project for the Snake River Plain study area.

1) Depth-to-water

a) Introduction

Evaluation of the depth to first-encountered water below land surface is a significant element in evaluating susceptibility of ground water to contamination, because areas where the ground water is close to the surface typically have a higher probability for ground water contamination. The Project took the most conservative approach and mapped first-encountered water because these are the first resources to be potentially impacted. The Project made no distinction as to whether the first-encountered water was in small, perched aquifers or deeper regional aquifers. Many of the domestic drinking water wells in the Snake River Plain are constructed in the shallowest aquifers, which adds to the importance of mapping first-encountered water. Depth-to-water values were developed by the USGS (Maupin, in press-a; Maupin, in press-b) using existing data and software to construct a GIS data set (Figure 2). The values that make up the zones were generated using water-level altitudes, land-surface altitudes, and selected computer software. This section on depth-to-water was extracted from Maupin (in press-a; in press-b).

b) Overview of Methods

Data from 1-degree DEM's (Digital Elevation Models) and the U.S. Geological Survey's GWSI (Ground Water Site Inventory) data base were used to construct a grid and a data set for each quadrangle. DEM's provided the land-surface altitude data and GWSI provided well data from which wells were chosen to best represent ground water conditions from 1980 to 1988. Universal kriging software was used to estimate water-table altitudes for first-encountered water at grid intersections for the Snake River Plain and western tributary valleys. ARC/INFO computer programs were used to estimate water-table altitudes for first-encountered water at grid intersections for the eastern Snake River Plain and some associated tributary valleys. Depth-to-water was calculated by subtracting estimated water-table altitudes from land-surface altitudes at the grid intersections. All depth-to-water values and locational attributes were then loaded into ARC/INFO and contoured to depict the depth-to-water and standard deviation of error zones.

c) Data

A DEM is an array of altitude values representing ground positions at regularly spaced intervals. DEM's are created by the Defense Mapping Agency and are reformatted and distributed by the U.S. Geological Survey. One-degree DEM's are referenced horizontally on the geographic coordinate system (latitude/longitude) of the World Geodetic System of 1972 Datum (U.S. Geological Survey, 1987, p. 1, 5).

The DEM's were used to construct a grid of land-surface altitudes. Water-table altitudes were estimated at grid intersections. Grids were constructed by splitting 1-degree DEM's into twenty 1:100,000-scale quadrangles and reducing

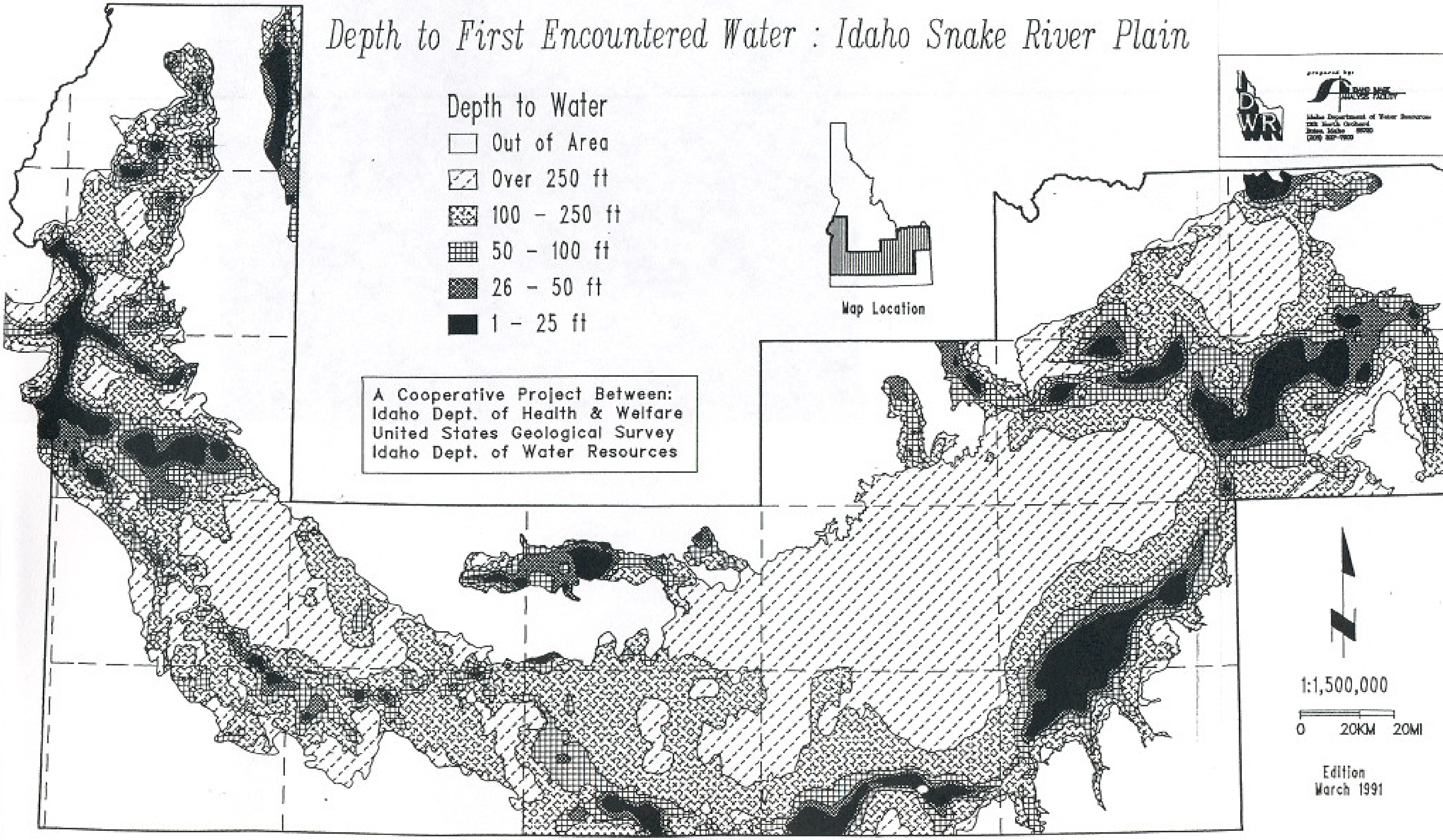


Figure 2: Depth-to-water first encountered map, Snake River Plain, Idaho.

the number of altitude points to one per square mile.

Well data were acquired from the GWSI data base, which is maintained on the USGS Idaho District Prime computer in Boise, Idaho. Data in GWSI include location, depth, altitude, and water levels of wells. All wells in the study area for which total depth of well, land-surface altitude, and water levels for the period 1980 to 1988 were available were identified from the GWSI data base. Only wells with water-level data for this period were used for analysis.

The data were refined additionally to develop a data set that best represented water-table conditions. Artesian wells were excluded from the data set to avoid false representation of the water table. An artesian well is a well that penetrates the upper confining layer of an artesian aquifer. In this case the water level will rise above the level of the confining layer, but not necessarily reach the land surface. If these wells had not been eliminated from the data set, their high water levels would have erroneously increased the estimated water-table altitudes and created a more shallow depth-to-water value than was actually present. Wells with known total depths were selected so that water levels from wells of unknown depths were not integrated with water levels from wells of known depths. This process was necessary to accurately map first-encountered water. No attempt was made to exclude wells completed in perched-water zones.

March water levels were selected for the eastern Snake River Plain because at that time the water table is relatively stable and less affected by water use than at other times of the year. March water levels also represent most of the available data because mass water-level measurements on the Snake River Plain are conducted in early spring. If more than one March water-level measurement in the last 8 years was available for a well, the shallowest water-level measurement was selected. Where few data were available on the eastern Snake River Plain, a water level obtained between January and April was selected. Where few data were available for the western Snake River Plain and in tributary valleys, June and July measurements were selected because they represent the shallowest water levels and the majority of data available. Water-level measurements were converted to water-level altitudes in feet above sea level to relate measurements to a standard datum.

To develop a depth-to-water map representing first-encountered water, the shallowest representative wells were selected. Wells 100 ft deep or less were selected first from the data set, and deeper wells within 1 mi or less of a selected well were deleted. If there was more than one well 100 ft deep or less within 1 mi, all wells were retained and water-table altitudes were examined. Where there were no wells 100 ft deep or less, wells 101 to 300 ft deep were selected from the data set and deeper wells were deleted. This process was repeated until no wells remained.

d) Software

Universal kriging was the statistical technique used to estimate water-table altitudes at grid intersections from measured water levels for irregularly spaced selected wells. Kriging is a two-step process in which data measurements are used to determine a mathematical definition for a semi-variogram. The semi-variogram was used to generate estimated water-table altitudes at the supplied grid intersections (Skrivan and Karlinger, 1980, p. 2-3). The semi-variogram is a diagram of the irregularity of the difference of the data measurements compared with the distance between the data points (Dunlap and Spinazola, 1984). Unlike other interpolation methods, kriging provides a Standard Deviation of Error (SDE), or a square root of the variance, for each estimated water-table altitude. Low SDE values signify a greater confidence than high SDE values. If SDE values are low, estimated water-table altitudes are closer to actual water-table altitudes than if SDE values are high. Figure 3 is a map of SDE values for the depth-to-water map in the Snake River Plain.

Well data from adjoining quadrangles were incorporated into each kriging operation to improve estimates along quadrangle boundaries. Depth-to-water values were calculated as the difference between land-surface altitudes and kriged water-table altitudes. If negative depth-to-water values were calculated at grid intersections that did not intersect with water bodies, the SDE values were used to recalculate the depth-to-water values below land surface. If depth-to-water values still remained negative, the kriging program was rerun and a new semi-variogram was developed.

The methods of combining software and data to estimate the water-table altitudes for the eastern Snake River Plain were different from the methods used for the surrounding tributary valleys. The universal kriging method could not be used to estimate the water-table altitudes for the surrounding tributary valleys in an acceptable manner because of the shallow ground water conditions and the elongate nature of the valleys. The estimating and contouring capabilities of ARC/INFO were used because they were capable of supplying more reasonable values over a larger area.

Selected wells for the eastern Snake River Plain tributary valleys were organized into an ARC/INFO data set with three-dimensional and spatial qualities. Water-table altitudes

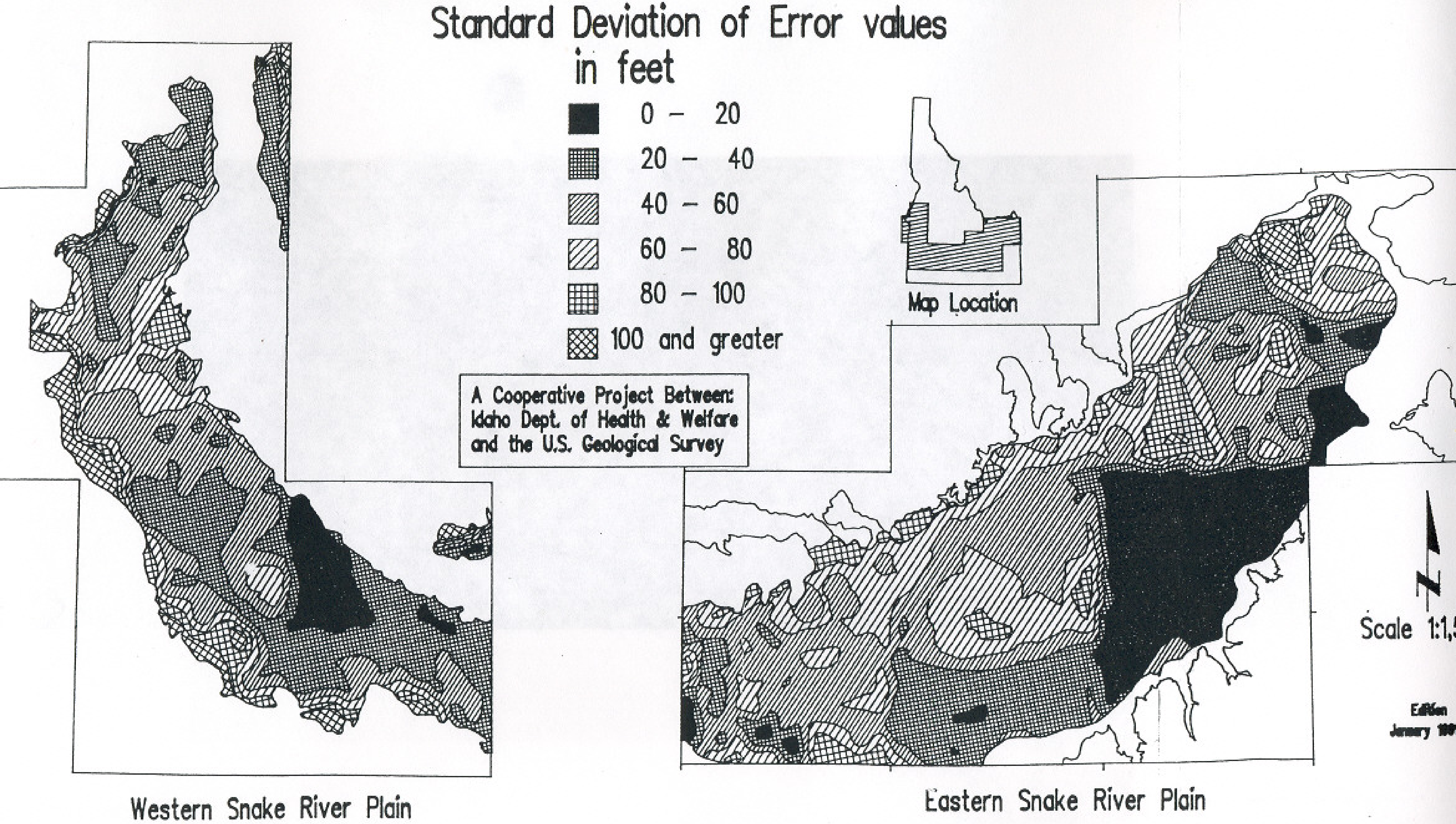


Figure 3. Zones of standard deviation of error values. Standard deviation of error values for eastern and western halves do not correspond exactly because each was kriged separately.

represented the z axis; latitudes and longitudes represented the x and y axes. Estimations of water-table altitudes at supplied 1-mi^2 grid intersections were facilitated by an inverse weighted distance nine-neighbor algorithm. This was the preferred ARC/INFO method for estimating regularly spaced water-table altitudes for a surface with irregular hydrologic characteristics. Depth-to-water values were calculated by subtracting water-table altitudes from land-surface altitudes for all grid intersections within the eastern Snake River Plain tributary valleys.

ARC/INFO-estimated water-table altitudes within the eastern Snake River Plain tributary valleys were reasonable and acceptable. Estimations of water-table altitudes where tributary valleys join the eastern Snake River Plain were compatible with kriged water-table altitudes. One difference between the two methods is that ARC/INFO does not generate SDE values. Another difference is that universal kriging honors exact well data at locations where wells fall on grid intersections, whereas ARC/INFO does not.

After depth-to-water values for the eastern and western Snake River Plain were calculated, they were combined into a single ARC/INFO data set and contoured. Corresponding attributes such as SDE values were added to the data set and contoured. Depth-to-water zones were created from the contours and shaded in Figure 2.

e) Rating System of Depth-to-Water Layer

The depth-to-water maps were rated on a point basis to obtain values relative to ground water susceptibility to contamination (Figure 2). Areas with smallest depth-to-water values are considered to represent the greatest danger to ground water contamination, and hence were given the greatest point rating. Areas with large depth-to-water values were believed to represent the smallest risk to ground water contamination, and therefore received the smallest point rating. The following ratings were used by the Idaho Ground Water Vulnerability Project for the depth-to-water maps. This point rating scheme may be changed in the future after a comparison to ground water monitoring data.

Depth-to-Water Ranges (feet)	Rating (points)
1 to 25	50
26 to 50	35
51 to 100	20
101 to 250	10
> 250	1

2) **Recharge**

a) Introduction

The "recharge" component of the Ground Water Vulnerability Model represents water that penetrates the ground surface and percolates to the water table below (Figure 4). The recharge component can be difficult to assess but is crucial for vulnerability evaluation. Recharge may transport contaminants from the surface, therefore, the higher the volume of water that penetrates the ground surface the higher the possibility of contaminants reaching the aquifer. Many recharge models use multiple data inputs such as precipitation, air temperature, and conveyance loss. Much of this data is site specific and expensive to obtain.

The most cost effective method to rate recharge in the Snake River Plain was to classify the various land cover types such as man made irrigation, forestland, dryland agriculture, rangeland, etc. On the Snake River Plain, precipitation is generally less than 10 inches per year, hence precipitation supplies very little recharge to the aquifers. Man made irrigation is a much greater component of recharge to the Snake River Plain. By classifying the different types of land cover, a good estimate of relative amounts of recharge can be developed that meets the needs for ground water vulnerability assessment.

It is important to note that using land cover as an estimate for recharge combigns factors from natural sources (rangeland, dryland agriculture, forest, etc.) and man made sources (gravity and sprinkler irrigation). As time progresses the man made portion of recharge can change significantly, whereas the natural component of recharge should remain relatively the same. This combination of natural and man made sources makes the recharge layer a combination of susceptibility and contaminant loading potential.

b) Overview of Methods

The "recharge" map combined three digital layers, or maps, that indicated types of land cover. The first layer outlined Irrigated and Dry Agricultural Stratum for Southern Idaho (Agricultural Stratum). This information was mapped by the Idaho Department of Water Resources. It was produced by delineating irrigated and dry farmland areas from 1:250,000 Landsat False Color Composite (FCC) images flown in 1986.

The second layer consisted of Irrigation Water Management (IWM) data developed by the USDA Soil Conservation Service. This layer represents irrigated farmland as either sprinkler-

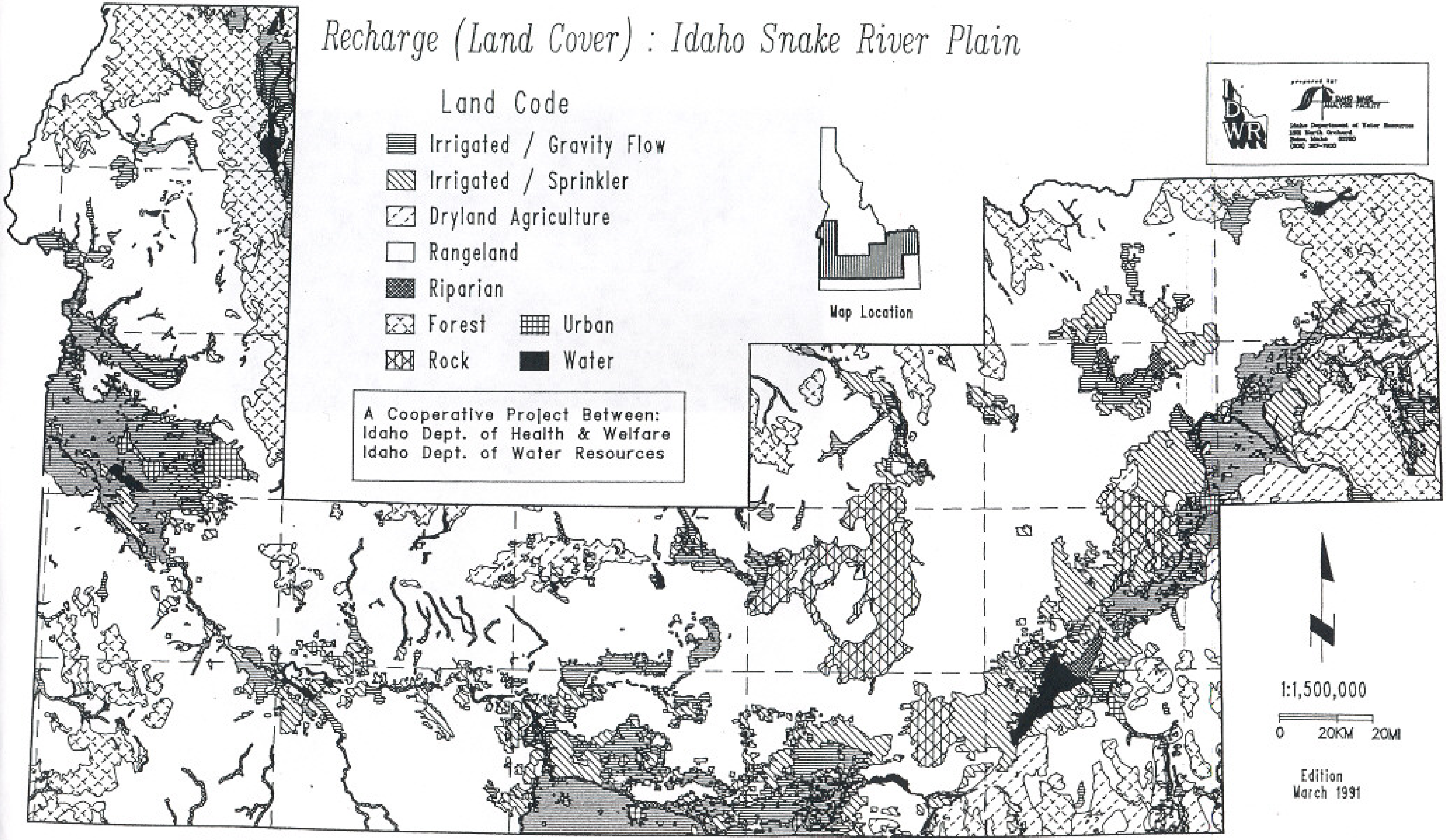


Figure 4: Recharge map Snake River Plain, Idaho.

or gravity-fed water delivery systems. The data were field checked for accuracy and mapped in 1983. Knowing the type of delivery system allowed the recognition of land with differences in water application rates. Generally, the gravity-fed systems apply water to the land at a higher rate than sprinkler systems. The rate of application is important because the higher the rate, the greater the recharge to the underlying aquifers.

The third layer was the Actual Vegetation Map of Idaho created by Steve Caicco (IDWR, in press). This layer was mapped at a scale of 1:500,000, so areas smaller than 1750 acres were not mapped. It contains over 118 vegetation types, categorized by species. The level of detail made the map too cumbersome for the vulnerability model because the scope of this project did not include differentiation of individual plant species. Thus, the specific vegetation types were aggregated into five general categories representing rangelands, agricultural lands, forests, lava flows, and riparian areas. For example, Whitebark Pine, Mountain Hemlock, and Lodgepole Pine were aggregated into the "Forests" category.

The joining of these three layers divided the region into irrigated and non-irrigated land. Irrigated lands were further divided into gravity- and sprinkler-fed water delivery systems. Non-irrigated land was divided by vegetation type with recognized levels of required precipitation. Each of these divisions isolated in some way the level of water applied and thus the aquifer recharge component.

c) Discussion

The Halo Effect

When joining the three layers of the recharge component, the outer boundaries of many regions did not match because the layers were based on different source data, and created at different times. The overlapping data produced a "halo" effect resulting in an indistinct boundary between areas of different land cover. When the "halo" was caused by conflicting source data, the IWM information was used because of its larger scale and greater accuracy.

Although more precise, the IWM was based on older information. To correct "time halo" effects, Landsat False Color Composite images(FCC's), aerial photos, and the comparison of adjacent areas were evaluated to determine irrigation system type.

Towns and Lakes

Urban and lake areas were left out of the vulnerability model for rating purposes and were used only as location markers on the final maps. Recharge in urban areas is much more diverse and site-specific than in the broader land cover types.

Therefore it was decided that the rating of these urban areas should be left to a more in-depth study or model.

d) Rating System of Recharge Layer

The "recharge" map was generated by merging the three sources of information on land cover. Each resulting recharge class was given the following point rating to be used in determining relative vulnerability. The sources of highest recharge were given the highest point rating. These point ratings may be adjusted in the future after comparison to ground water monitoring data. Figure 4 shows the distribution of these classes throughout the Snake River Plain.

Recharge Classes	Rating (points)
Gravity-fed irrigated land	50
Riparian areas	50
Sprinkler-fed irrigated land	40
Forests	30
Dryland agriculture	20
Rangeland	20
Bare rock (lava flows)	10
Urban areas	No rating
Surface water	No rating

3) **Soils**

a) Introduction

The soils layer is an important factor in determining ground water susceptibility because it acts as the first barrier to potential ground water contamination. For the purposes of this project, contaminants were assumed to have the same mobility and characteristics as water. Additional data layers can be developed in the future to evaluate the migration of specific classes of contaminants, whether it be solvents, various types of pesticides, or petroleum hydrocarbons. This study defined the soil layer as the uppermost 60 inches (5 ft) of land surface.

The Idaho Ground Water Vulnerability Project incorporated the State Soils Geographic Database (STATSGO) and SOILS-5 database developed by the U.S.D.A. Soil Conservation Service (SCS). STATSGO is a general soils database which consists of two parts; a spatial (map) component based on USGS topographic maps at a scale of 1:250,000, and an attribute data base consisting of tabular soils data. The SOILS-5 database was the source for the tabular soils data for STATSGO. SOILS-5 provides information on a broad range of chemical and physical soil characteristics, and develops interpretations for various uses of the soils based on these characteristics. Particular attributes that were pertinent to the vulnerability project were extracted from the SOILS-5 database and used in conjunction with the soils map (Figure 5).

A single STATSGO soil mapping unit may include several soil series and their phases. Soil "series" are defined as "a collection of soil individuals essentially uniform in differentiating characteristics and in arrangement of horizons" (Brady, 1974). Series are typically derived from the same kind of parent material by the same genetic combination of processes. Series are established on the basis of profile characteristics, which include the number, order, thickness, texture, structure, color, organic content, and reaction (acid, neutral, or alkaline) of the various horizons. A soil "phase" is a subdivision of a soil series on the basis of some important non-pedogenic factor such as surface texture, erosion, slope, stoniness, or soluble salt content.

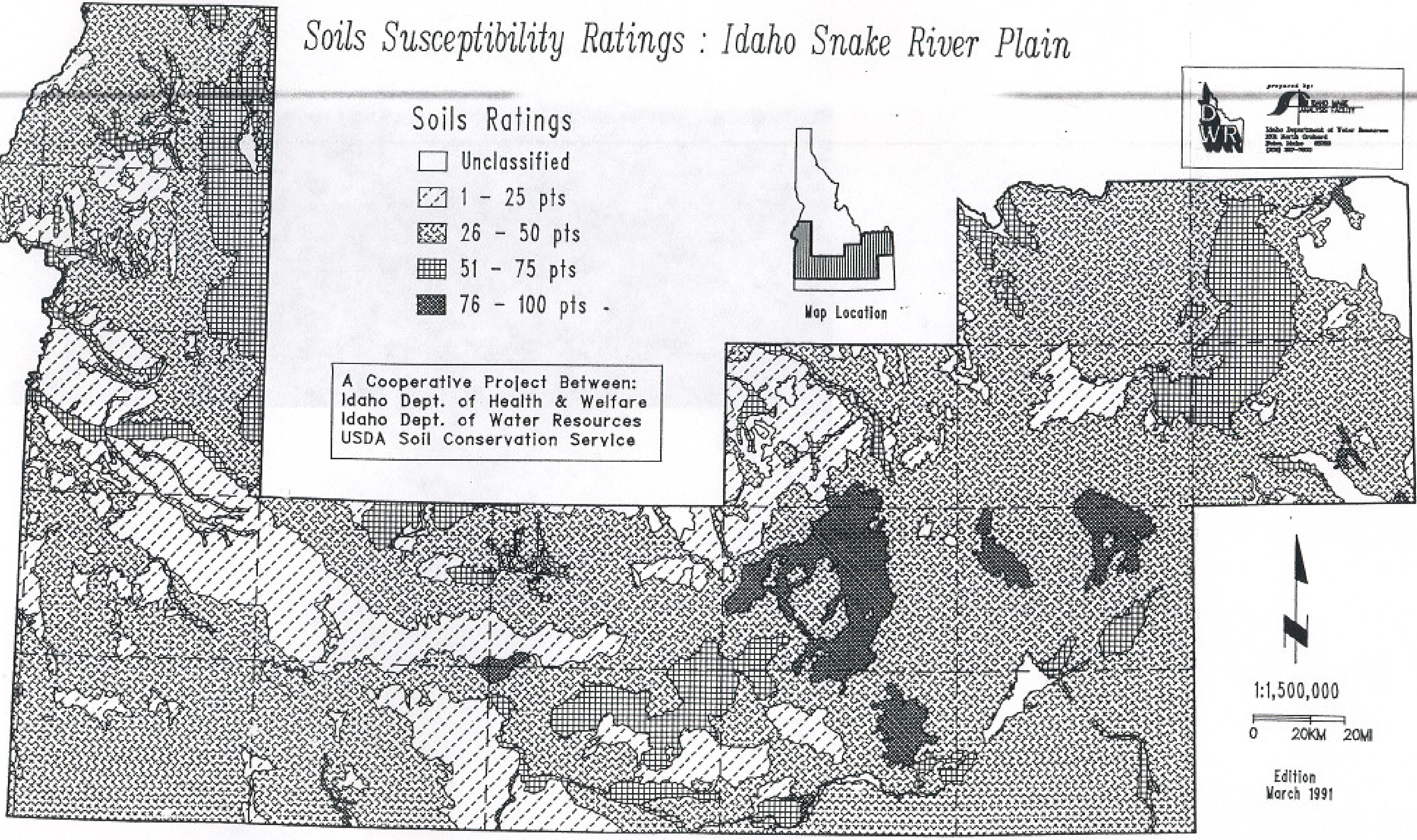
b) Rating System of Soils Layer

Several soil-landscape characteristics were chosen to be included in the soils layer from the information available in the SOILS-5 database. These characteristics are: 1) permeability of the most restrictive layer; 2) depth-to-water table within the soil horizon; 3) depth to bedrock; and 4) flooding frequency. The point rating systems for these characteristics may be changed in the future as more information is gained, and after comparison to ground water monitoring data.

1) Permeability

Permeability class of the most restrictive layer was chosen because it was thought to reflect a greater range of soil characteristics that influence water movement than did soil texture alone. Permeability class uses many characteristics, which include; texture, structure, pore-size distribution, density, clay mineralogy, consistence, organic matter content, and rooting distribution.

Permeability class was rated on a point scale to represent the relative influence of a particular class to ground water susceptibility. The following is a table of the point rating scheme for the permeability class of the most restrictive layer:



Soils map, Snake River Plain, Idaho
STATSGO data is preliminary and is subject to change

PERMEABILITY (in./hr.)		RATING (points)
no soil		20
very rapid	(>20.0)	20
rapid	(6.0-20.0)	16
mod. rapid	(2.0-6.0)	12
moderate	(0.6-2.0)	8
mod. slow	(0.2-0.6)	6
slow	(0.06-0.2)	4
very slow	(<0.06)	2
limiting layers (e.g. duripan)		2

As each soil series was evaluated, the particular horizon sequence, horizon thickness, permeability of horizons other than the most restrictive layer, and other unique features were noted. These features were then evaluated in terms of how they affect soil water movement in determining the final permeability class chosen for that soil.

If a soil had strongly contrasting permeability classes within 60 inches of the surface (moderate rating of 8 pts overlying very rapid with a rating of 20) the rating was typically increased to reflect the extremely high permeability of the subsoil. In this example, the rating would change from 8 to 20.

The rating was also increased if the thickness of the layer of lowest permeability, such as an argillic horizon was less than 6 to 12 inches. If the high seasonal water table was shown to be near or within a surficial horizon of higher permeability the rating for that higher permeability class was used. Soils with very slow permeability and cracking, shrink-swell clays were treated as if they were in the wetted, closed condition.

The rating of soils with thin (< six inches), moderately or weakly cemented duripans over sand or gravel was increased to reflect the lowest permeability in the portion of the profile above the duripan. If there was a duripan less than six inches thick overlying bedrock, the duripan was ignored and the permeability of the least restrictive layer above the duripan was used.

2) Depth to water-table

Depth to water-table (presence or absence within the upper five feet of soil) was chosen to supplement in more detail the layer on depth-to-water that was developed for this project by the USGS (Maupin, in press-a; Maupin, in press-b). This characteristic was included in the rating scheme because ground water within the uppermost 60 inches of soil poses a situation particularly susceptible to ground water contamination. For instance, during the irrigation season water-tables are often the highest and this coincides with those times when agricultural chemicals are more likely to be in use. The high water-tables identified by the SCS may in some cases represent perched, shallow aquifers of limited areal extent. For the purposes of this project all areas where high seasonal ground water was identified were assumed to be leaky and in hydraulic connectivity with deeper aquifers.

The following is a table of the point rating scheme for the depth to water-table class:

DEPTH TO WATER-TABLE	RATING (points)
water-table within 60 inches	8
water-table greater than 60 inches	0

3) Depth to Bedrock

Depth to bedrock adds information that is applicable to the evaluation of travel times to ground water, particularly when considered together with permeability and depth-to-water information. Depths greater than five feet are lumped into one class. This characteristic was chosen because large portions of Idaho (particularly southern Idaho) are underlain by relatively uniform basalts, whose transmissive properties have been studied and are reasonably well understood. Depth to this material is therefore of importance. The occurrence of different bedrock types was not considered.

DEPTH TO BEDROCK	(inches)	RATING (points)
absent	(no soil)	10
very shallow	(0-10)	9
shallow	(10-20)	8
mod. deep	(20-40)	5
deep	(40-60)	2
very deep	(>60)	1

4) Flooding Frequency

Flooding Frequency was chosen to give an additional representation of recharge, which can act to move pollutants more quickly towards ground water. It was felt that when a flooding event occurred over a given soil an additional pressure head would develop. The more frequently a soil was subjected to flooding, the greater the rate of water movement, particularly in a vertical direction. Flooding frequency, as well as depth to water-table, can be considered landscape factors rather than soil factors. They give more detailed information on the relative susceptibility of ground water to pollutants moving through the soil in a particular geomorphic setting. Factors such as the severity of flooding, its timing in relation to soil moisture conditions and agricultural chemical applications, and the potential for removal of pollutants to surface water were not considered.

The following is a table of the point rating scheme for the flooding frequency class:

FLOODING FREQUENCY	RATING (points)
frequent	5
occasional	4
rare	2
none	0

c) STATSGO Soil Unit Weighting System

As mentioned before, many of the STATSGO soils units consist of several soil series and their phases. The ratings for the various series and their phases were weighted to reflect the percent of the STATSGO mapping unit that each soil series and/or phase occupied. The weighted values for each soil series and/or phase were then summed to arrive at a susceptibility rating for the entire mapping unit as follows:

1) For each mapping unit, from information on composition supplied by the SCS, the dominant soil series and phases were identified. The number of series and/or phases to include in developing a rating was determined by this procedure:

a) If one soil series and/or phase does not equal 85% or greater of the entire mapping unit, then the next most dominant soil series and/or phase was added. If their combined area is less than 85% then a third series and/or phase was added.

b) With three or more series and/or phases, their combined percentage need only be greater than or equal to 80% of the entire mapping unit.

2) The numerical ratings for each of the four factors were summed for each of the dominant soil series and/or phase found in the mapping unit and multiplied by the percentage of the entire mapping unit that each soil series and/or phase occupies. These values were then summed over all soils in the map unit. This is illustrated in the table below.

SOIL SERIES	%	PERM.		DEPBDRK		DEPWATR		FLDFREQ		RATING
Newdale	24 *	(2	+	1	+	8	+	4)	=	360
Wheelerville	15 *	(20	+	8	+	0	+	0)	=	420
Rexburg	57 *	(8	+	1	+	0	+	0)	=	513
TOTAL	96% pts									1293

3) The summed value (1293) was then normalized for the percentage of soils in the map unit used in the calculation (96%). In this case, 1293 would be divided by 96 to come up with a weighted soils susceptibility rating of 13 points for that STATSGO soils unit.

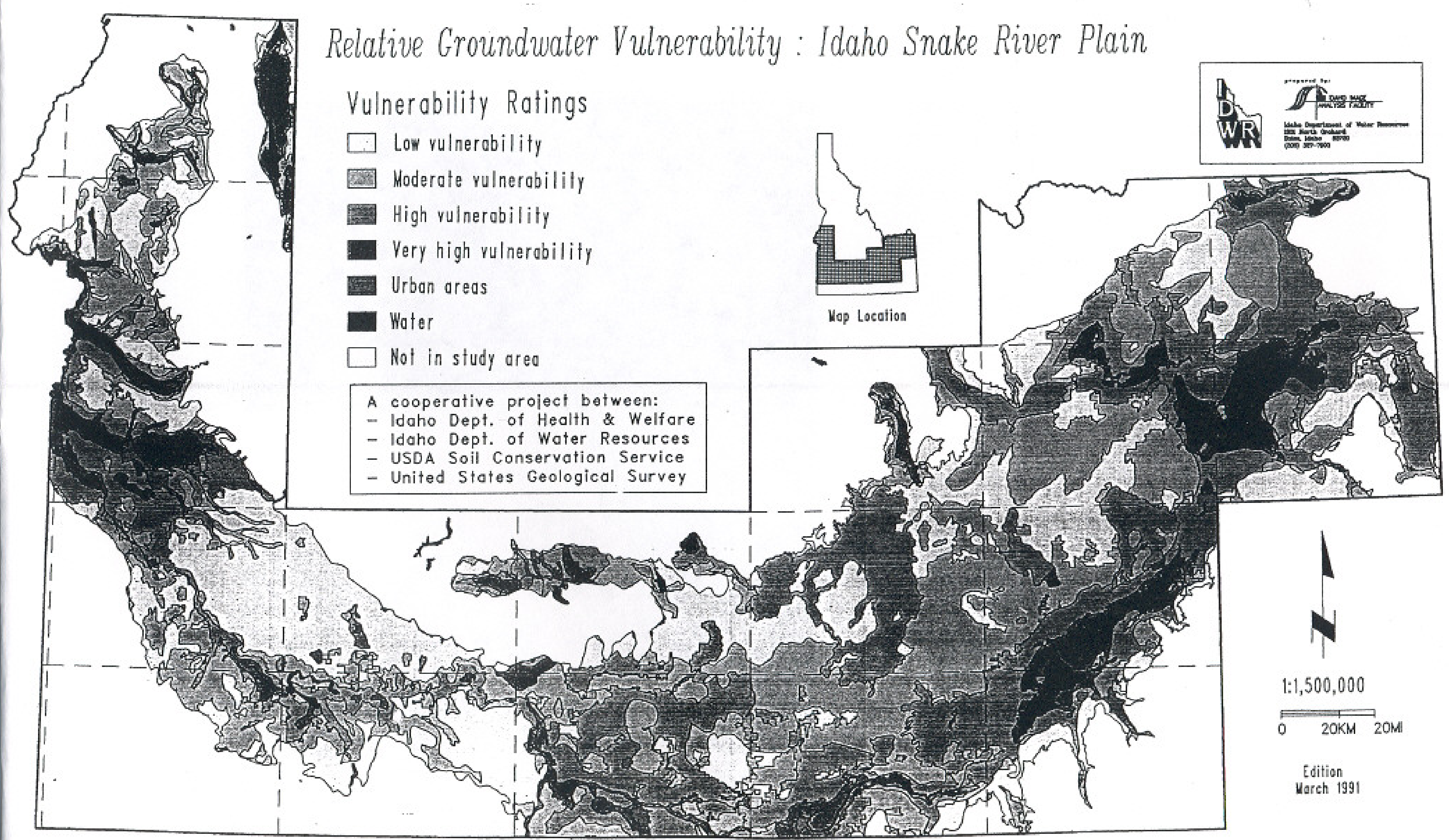
The weighted score for each STATSGO mapping unit was then multiplied by three to determine the final soils susceptibility rating. This gives a maximum possible rating of 120 points (although scores did not exceed 100 points), giving the soils layer a maximum relative importance of 2.4 times over the other two layers. The soils layer received a greater weighting because the soils layer incorporates more than one criteria which determine susceptibility assessment (permeability, depth to bedrock, depth to water-table, and flooding frequency), whereas the depth-to-water and recharge layers only rate one criteria (Mike Ciscell, former Remote Sensing Analyst, IDWR, personal communication, January, 1991).

VULNERABILITY MAP

1) Development of the Vulnerability Map

The Ground Water Vulnerability map (Figure 6) was generated by merging the three maps (depth-to-water, recharge, and soils) into one map using GIS techniques. The point ratings from each map were added together to create a final map with additive vulnerability point scores.

The vulnerability map was then broken into low, moderate, high, and very high vulnerability categories. The division points for these categories were derived by graphing the relationship of total acres versus total vulnerability score (Figure 7). The top ten percent with the highest


Relative Groundwater Vulnerability : Idaho Snake River Plain
Vulnerability Ratings
Low vulnerability
Moderate vulnerability
High vulnerability
Very high vulnerability
Urban areas
Water
Not in study area
A cooperative project between:
– Idaho Dept. of Health & Welfare
– Idaho Dept. of Water Resources
– USDA Soil Conservation Service
– United States Geological Survey
Map Location
1:1,500,000
0 20KM 20MI
Edition
March 1991

vulnerability ratings were placed into the very high vulnerability class to reduce the skewness of the distribution. The remaining distribution was then divided equally into thirds, with a final breakdown of 30% = low, 30% = moderate, 30% = high, and 10%=very high (Figure 8). This is a first approximation at splitting out the categories which will be refined in the near future after comparison of the vulnerability maps to ground water monitoring data.

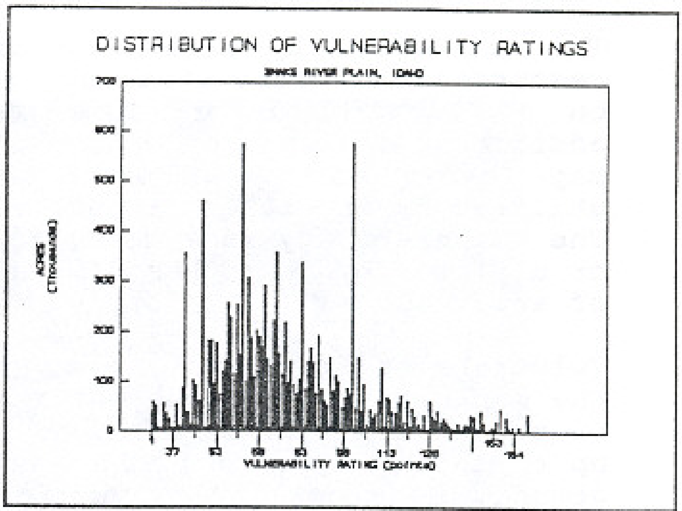


Figure 7: Graph showing the distribution of relative vulnerability ratings versus total acres within the Snake River Plain.

2) **Uses of Vulnerability Maps.**

The vulnerability maps are designed to serve as a tool for prioritization of ground water management activities. Areas of higher vulnerability can be given priority for prudent ground water protection measures in order to assure that limited resources are effectively used in areas of greatest concern. Programs which can utilize vulnerability maps include underground storage tanks, wellhead protection, ground water monitoring, public water supplies, agricultural chemicals, waste water management, best management practice (BMP) implementation and development, hazardous waste management, state and federal superfund programs, land use planning, State underground tank insurance agencies, and public information.

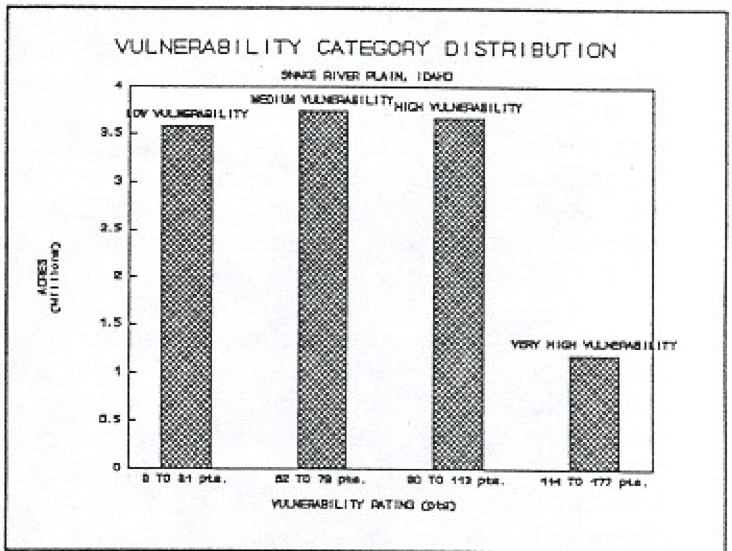


Figure 8: Graph showing the distribution of vulnerability categories within the Snake River Plain.

The vulnerability maps also provide a valuable data base resource for future studies. Since the maps were developed on a GIS, all information can be readily accessed, and additional information can be added to them. The individual map layers on soils, depth-to-water, or recharge can be utilized by any other project requiring similar information. The vulnerability maps can also be merged with, compared to, or utilized by any other GIS data layer to perform a variety of analyses.

Vulnerability maps provide a very cost effective approach to the management of ground water quality activities. The cost of producing these maps are a fraction of the cost to clean up contaminated ground water resources. Their benefits for ground water quality protection far outweigh their initial cost of production.

3) Limitations of Vulnerability Maps

The vulnerability maps described in this document highlight areas sensitive to ground water contamination in a generalized way. Because of the scale of mapping (1:250,000 for soils and depth-to-water layers, 1:100,000 for the recharge layer) that was incorporated in the development of these maps, they should be used for regional program planning purposes only, and should not be used for making site specific decisions such as whether to site a landfill in a particular location. For instance, there could be smaller areas of high vulnerability within low vulnerability areas and vice versa. The maps can be used as a first-cut approximation of the vulnerability of certain areas, but more in-depth studies must be performed for site-specific applications.

These maps do not show areas that will be contaminated, or areas that cannot be contaminated. Likewise, these maps do not show if a particular area has already been contaminated. Whether the area will have ground water contamination depends upon the likelihood of contaminant release, the type of contaminants released, and the frequency of that release. These maps only consider the ability of water to move from the land surface to the water table and do not consider the individual characteristics of specific contaminants.

Users of these maps should keep in mind that a low vulnerability rating is not an invitation for uncontrolled land-use practices. A low vulnerability rating merely suggests that there is a lower chance of ground water contamination than in areas of higher vulnerability. Just about any ground water resource can be contaminated if it is subjected to improper land use practices. The use of substances such as a restricted-use pesticide in a low vulnerability area should only be done under the oversight of an effective ground water monitoring program to assure that the substance is not adversely affecting ground water resources.

FUTURE GOALS

1) **Statewide Mapping**

A primary goal of the Idaho Ground Water Vulnerability Project is to develop a statewide map. Accordingly, mapping of the existing layers will be expanded on a statewide basis as much as funding levels and data availability allow. In this way, the affected programs can be addressed on a statewide basis as soon as possible.

2) **Pilot Projects**

Additional layers incorporating data not previously evaluated will be mapped by the Idaho Ground Water Vulnerability Project on a pilot project scale in the near future. This will help determine whether additional data layers can be developed on a cost-effective basis to further refine the vulnerability maps. Possible projects include an updated land-use layer, a vadose-zone layer, an updated recharge layer based on consumptive use, or other DRASTIC data layers that have not been developed yet.

3) **Field Verification**

Field verification is an important aspect to developing ground water vulnerability maps. Field verification is performed by overlaying known ground water quality data on the vulnerability maps and observing whether there is a correlation. After taking local ground water flow directions into account, the majority of contamination problems should be located in areas marked as high or very high vulnerability. Figure 9 shows an initial comparison of the vulnerability map for the Snake River Plain to ground water monitoring data collected by Idaho's Statewide Ground Water Monitoring Project during the summer of 1990. In this study, 52 wells were sampled in the Snake River Plain, and out of those wells 13 had anomalous detections of triazine herbicides, VOCs, and nitrates. All wells that had anomalous levels of contaminants were located in high or very high vulnerability categories, or in urban areas which were not rated by this study. Although this is not a statistically-valid comparison, it certainly lends credibility to the vulnerability maps.

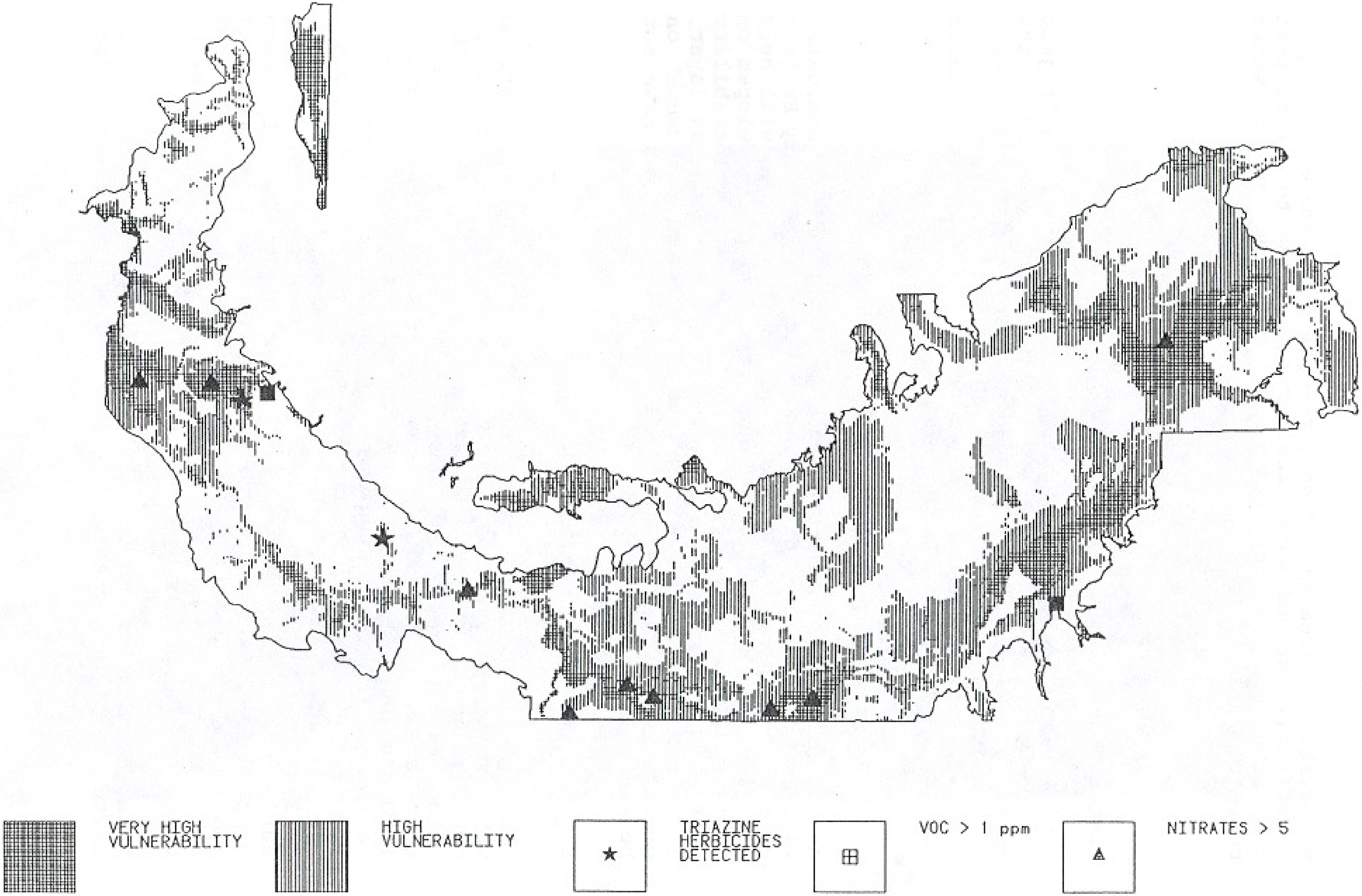


Figure 9: Comparison of data from the 1990 Statewide Monitoring Project to High and Very High Vulnerability Categories. Low and Medium Vulnerability Categories not shown.

Initial comparisons with other monitoring data also show good correlations. Additional comparisons will be made in the near future to form statistically-valid interpretations of the effectiveness of the maps. Comparison studies with monitoring data will be an ongoing element in refinement of the vulnerability maps. The point rating schemes may be adjusted in the future in response to this comparison with ground water monitoring data after the results from the statistically-valid studies.

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