MULTIVARIATE THEMATIC MAP VISUALIZATION OF THE OREGON 2001 DROUGHT

by

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ABSTRACT

The visualization of climate patterns is a major theme in cartography. Short-term dramatic weather events such as hurricanes and tornado outbreaks are mapped and displayed immediately in order to capitalize on the sensational nature of the events, and to quickly and accurately convey the information to emergency workers and the general public. Sustained weather events such as drought fail to capture widespread public interest, even though the economic and social repercussions of a drought may rival or exceed that of severe flooding or wind storms.

Drought occurs in almost all climate zones. It is considered a normal feature of a region's climate and is not a rare or random event. Given the diversity of Oregon's topography and weather patterns, the specific characteristics of drought vary from one part of the state to the next. Despite this variability, the full impact of drought is largely determined by political and economic factors as well as hydrologic and topographic regimes of the region. The water availability in Oregon is essentially fully appropriated, and its use heavily governed. Therefore, anthropogenic factors are as important as natural factors when visualizing drought.

This research paper will introduce new tools and methods for visualizing long-term weather events such as drought. Many variables must be included in order to characterize an event as nebulous as drought. This research paper will show that by utilizing advanced computer graphics software, many of these variables can be succinctly and clearly displayed on a single map. This thematic map visualization research will hopefully serve as a communication tool that may draw more attention to less spectacular weather events such as drought, and in turn elicit adequate public response.

INTRODUCTION

"The first step in developing adequate solutions is a thorough knowledge of the facts that exist and when, where, and how they vary over time. Then these facts must be understood and communicated. Information capable of being mapped is almost unlimited in variety; so are the needs and objectives of map users."

\- Howard T. Fisher, 1982

The visualization of a specific weather or climate event is impossible to achieve without first understanding the phenomenon itself. Thematic cartography can be viewed as a theatrical stage, with the event in question being the play that is performed on it. A drought, like any other natural disaster, must include in its definition humans and their use of the land. Droughts are a normal part of the planet's climate, with every geographic location being susceptible to unusually dry and hot weather. What sets droughts apart from other natural disasters are their temporal aspects: they are often measured in years. Droughts also directly impact agriculture, and with the production of food being one of the most basic needs of humans, they tend to lead to social upheaval. In light of such potential problems, communication tools such as maps take on increased importance.

The full range of possible social consequences of drought broadens as the spatial extent of drought increases. On the local level farms and businesses often suffer income loss, increased debt, bankruptcy and dislocation. Regionally, droughts disrupt economic sectors, increase unemployment and can lessen overall social stability. On the national level, they tend to cause widespread health problems, food shortage, and foreign trade losses. Finally, on the global level, droughts may produce starvation and famine, international conflicts, and overall disruption of social infrastructures (Riebsame 1991). This global impact is best exemplified by Somalia in the early 1990s and Ethiopia in the mid 1980s. Yet one must not confuse drought with famine and other social conflicts. Often famine is caused not by the lack of food, but by the poorly coordinated distribution of food. Governments in agriculturally marginal areas often use drought as an excuse to impose order, thus using starvation as a weapon. In America, droughts tend to manifest themselves economically, rarely leading to mass social disruption.

Given its inherent variability, drought should not solely be regarded as a reoccurring climate event. The impact of drought is mostly the result of a natural event interplaying with the demand a particular region places on its water supply. There has been a continual effort to accurately define drought. The U.S. Weather Bureau is the source of one of the earliest drought indices in America. They defined drought as "any period of twenty-one or more days with rainfall thirty percent or more below normal." This definition proved to be too liberal. Using these parameters, it identified sixty-two droughts in a mere three year period in the District of Columbia.

The National Drought Mitigation Center (NDMC) conceptually defines drought as "… a protracted period of deficient precipitation resulting in extensive damage to crops, thus resulting in loss of yield." In this definition the impact of drought on agriculture is of foremost concern. Another definition provided by Palmer (1965) that is still in use today defines drought as "An interval of time, generally months or years, when actual moisture supply consistently falls short of the climatically appropriate moisture supply" (Taylor, 1999).

Rather than one blanket statement used as a definition, the NDMC breaks drought into three individual perspectives. The first is meteorological drought. This is the easiest perspective to understand and is what cartographers almost exclusively use to map drought. Meteorological drought is simply a region specific period of unusually low precipitation. Although this is the genesis of drought, it is nearsighted to only map drought in this way. Drought is a natural reoccurring aspect of climate. How humans respond to drought should also be included in a thematic of the subject.

The second perspective is agricultural drought. This is measured using the difference between actual and potential evapotranspiration, reduced ground water or reservoir levels, and soil water deficit. This definition accounts for the variable susceptibility of crops during different stages of development because lack of water impacts vegetation differently depending on its maturity level.

The last perspective is hydrologic drought. Hydrologic drought focuses on the effects that low levels of precipitation have on surface and subsurface water supply. In other words, hydrologic drought is more concerned with how lack of precipitation influences the hydrologic cycle. This type of drought is out of phase with precipitation and takes longer to manifest itself than the other types of drought. This is because it takes longer for precipitation deficiencies to be revealed in the various stages of the hydrological system such as soil moisture, stream flow, and reservoir levels.

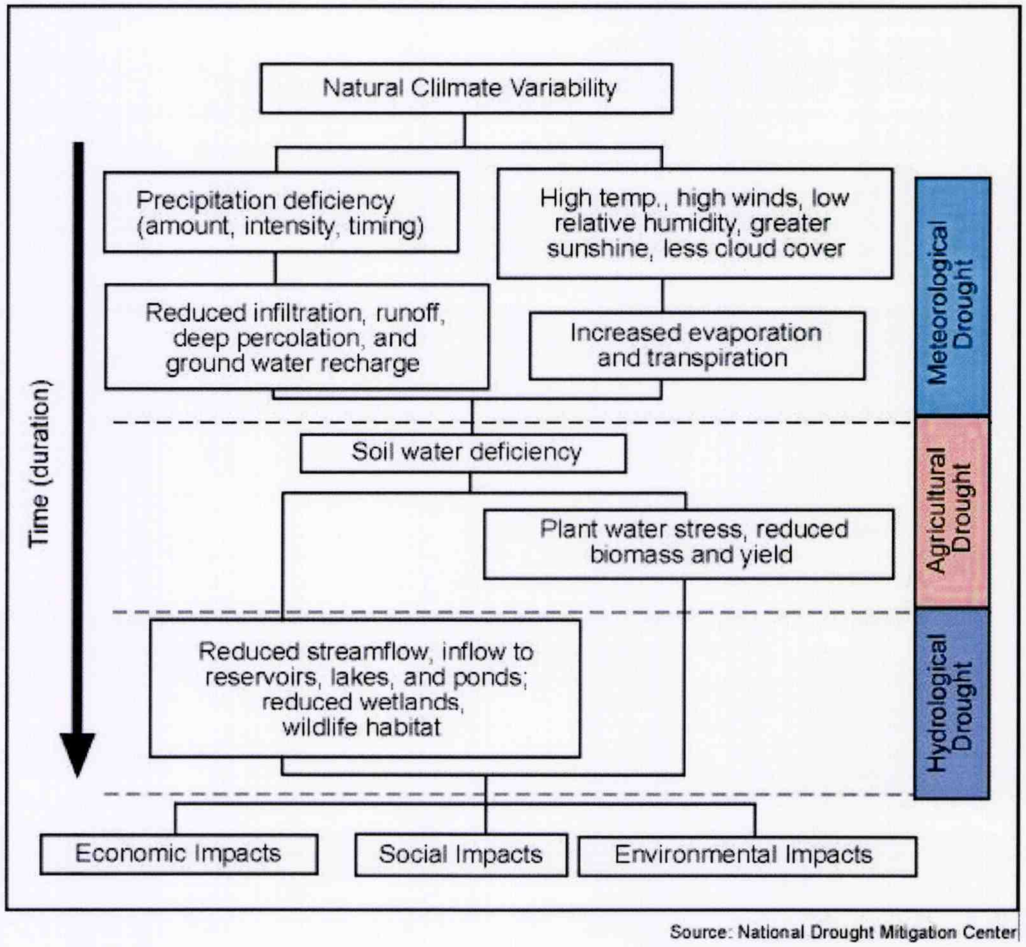

Figure 1. Sequential Impacts of Drought.

Water in storage systems such as dammed rivers and reservoirs are often used for multiple and competing purposes, such as flood control, irrigation, wildlife habitat, navigation, and recreation. This competition quickly escalates during prolonged drought periods. **Figure 1** illustrates the sequence of impacts linked with meteorological, agricultural, and hydrological drought. Notice that hydrologic drought is the final step before social and economic impacts are realized.

The impact of drought can be seen as being closely tied to governmental politics, business practices, and societal views of a region such as the Pacific Northwest. Discrete plans for dealing with drought have shown to be effective, but must already be in place in order to mitigate the stress and economic hardship of the local people, and to avoid wasting limited relief funds. Within these plans must be appropriate communicative tools such as thematic maps that address and illustrate the problem given the unique physical and meteorological characteristics of Oregon.

The objective of this research is to experiment with modern computer graphic programs to create new multivariate maps displaying three key indicators of drought in Oregon: declaration of drought per county, precipitation, and river discharge. Declaration of drought can occur on three different governmental levels: county, sate, and federal.

SOURCES OF DROUGHT RELATED DATA AND INFORMATION

Declaration of drought first occurs on the county level. This consistently triggers declaration of drought on the second governmental level, the state. For declaration of drought to reach the federal level, extensive data pertaining to economic hardship as a result of the drought must be presented to the Federal Emergency Management Agency. The schism between state and federal declared drought represents the financial ability of the two governmental levels to mitigate the needs of the region.

Precipitation is more difficult to spatially quantify. Two hundred and eleven rain gauge stations monitored by the USGS exist in Oregon. These stations measure in inches the amount of rainfall that occurs on a daily basis. Only seventy-six contained records accurate enough to yield mean annual figures. As seen in **Figure 1**, meteorological drought includes precipitation deficiency as a result of natural climate variability. This deficiency is measured by amount, intensity, and timing. Because annual mean precipitation data across the state of Oregon are utilized, all three of these measures of precipitation are reflected.

Precipitation across Oregon for the 2001 water year ranged from a high of ninety-five percent of normal in the Owyhee Basin of southeastern Oregon to a low of fifty-four percent of normal in the Umpqua and Rogue Basins of southwestern Oregon. The total precipitation in most parts of Oregon for the 2001 water year was either the driest or the second driest on record for the last one hundred years (USGS Water Resources Data, 2001).

Surface water is also monitored by the USGS in Oregon. This is accomplished by measuring the discharge of hundreds of rivers and streams across the state of Oregon. This discharge is measured in cubic feet per second per square mile (CFSM), which is the average number of cubic feet of water flowing per second from each square mile area drained, assuming the runoff is distributed uniformly in time and area. Discharge at many stations may not reflect natural runoff because of the effects of diversion, consumption, regulation by storage, fluctuation in precipitation, or other unknown factors. For this reason, the data gathered from these stations are adjusted to compensate for diversion, change in content of reservoirs, or other changes incident to use and control. If satisfactory adjustments are not possible, then the data from these few stations are not published (USGS Water Resources Data, 2001).

Ground water is also monitored by the USGS. The seasonal level of the water table reflects natural recharge and discharge, and indirectly reflects long-term climatic trends. Fluctuations in the water table are represented by seasonal averages of measurements made in shallow-aquifer wells. Five wells that comprise the Oregon

District portion of the U.S. Geological Survey's Office of Ground Water's Collection of Basic Records (CBR) network of wells are monitored. These are wells that show a high correlation to climatic variability. The water level of these wells are measured in feet below the land surface datum and recorded throughout the water year. (USGS Water Resources Data, 2001). These three indicators are used in this research to construct a multivariate thematic map of drought.

MULTIVARIATE THEMATIC MAPPING

The majority of thematic maps depict a single variable on a spatial framework. This is a method of communicating to the reader the structure and spatial variation of a single environmental phenomenon. Given the wide variety of possible data that may be used to visually communicate drought, a multivariate thematic map approach is best suited to illustrate the vast scope of this weather event. Multivariate maps allow the viewer to consider multiple variables simultaneously and possibly discover cross-correlations between theses sets of data (Robinson, et al. 1995). Multivariate thematic maps also vary greatly in conceptual design and complexity. A concise and intuitive graphic design approach must be used when constructing a multivariate map. This will allow the viewer to summarize various components of the multivariate thematic map quickly, thus coalescing these components into a concrete narrative.

This research uses modern computer software to help the viewer quickly discern the story that a thematic map tells. One of these programs is Bryce 5 by Corel. This is a powerful 3D landscaping and animation desktop computer program. Bryce 5 allows the user to create three-dimensional virtual environments, such as idyllic South American beaches or the forbidding mountains of Mordor in J.R.R. Tolkien's "Lord of the Rings."

Every facet of this virtual environment may be modified, such as light direction and intensity, atmospheric haze, fog, and shadows.

More important to the multivariate thematic cartographer is the ability of Bryce 5 to also create three-dimensional objects such as cylinders and spheres. These objects may then be rendered with a wide variety of materials. These materials are complex combinations of textures and values. Bryce 5 allows the user to combine textures and channel values that simulate any material found in the real world. This has the possibility of greatly expanding the intuitive nature of what a symbol in a thematic map is representing. For example, a thematic map may display cylinders whose variation in height represents varying volumes of water. Bryce 5 allows the thematic cartographer to make the cylinders also *resemble* water to a remarkable degree of realism, thus making the values the objects represents more intuitive. By graphically streamlining the intuitive process, one may be able to simultaneously display multiple variables on the same map while maintaining clarity.

Another major computer software program used in this research is Freehand 9 by Macromedia. Freehand 9 is a vector-based drawing application. It allows the user to create vector graphics that can be scaled and printed at any resolution, without losing detail or clarity. After importing a three-dimensional scene into Freehand 9, the cartographer can then add scalable text and symbols, along with other graphic elements such as arrows and borders. Freehand 9 also contains several color palettes that may be used to create a wide variety of hues. These powerful drawing and coloring capabilities make Freehand 9 ideal for finalizing a multivariate thematic map.

CARTOGRAPHIC METHODS

"Map design is illustrated by applying various procedures to a limited number of problems, producing alternative solutions. The virtues and limitations of different procedures can thus be meaningfully compared."

- Howard T. Fisher, 1982

The above quotation from Howard T. Fisher's "Mapping Information" succinctly illustrates a concept repeatedly encountered while conducting thematic map research: data and experimentation often drives the research. Thus, the researcher should be open to alternative methods of portraying the spatial data to be mapped, and must be willing to pursue these various avenues until they are exhausted possibilities.

In Oregon, the worst drought in thirty-one years occurred during the 2001 water year. The severe drought of 2001 was exacerbated by the political and economic regulations governing water rights and use. The hydrologic drought stage mentioned above was further stressed by State and Federal policies governing water use in times of low precipitation.

Figure three serves as the organizing structure guiding the data collected and mapping procedures initiated. Meteorological, hydrological and agricultural data were deemed necessary for an overall thematic map of drought because of the wide range of definitions the three factors cover. These particular factors were also chosen because of the resulting economic, social, and environmental impacts illustrated in Figure 3. This choice of data is the second of three basic factors that must be defined before a thematic map can be produced: (1) the study area of interest, (2) the information (values) to be displayed, and (3) the locations to which the information applies (Fisher, 1982). These factors are defined below.

The study area: The state of Oregon.

Information to be displayed: drought declaration per county (agricultural drought), precipitation (meteorological drought), and surface and ground water data (hydrological drought).

Locations to which the information applies: Counties (drought declaration), Climate Zones (precipitation), and Major Basins (surface and ground water).

The first step was to create a base map illustrating which counties in Oregon declared drought status during 2001. These data were found at the Oregon Emergency Management website: (http://www.osp.state.or.us/oem/images/drought_2001_trans.gif). Although the map at this web-link has in its legend drought declarations at the county, state, and federal levels, only state and federal declarations occurred. This is because it is highly unusual that Oregon's governor would not provide state assistance to a county if it individually declares drought.

A base map of Oregon was prepared in Macromedia Freehand 9. Each county in Oregon was represented by a closed polygon and placed into one of three layers: federal declaration, state declaration, and none. This allowed all counties in each layer to be quickly filled using one of three colors. The brown hues were chosen for their dry, "drought-like" appearance. See **Figure 2** below. Upon completion of the base map, it was mapped onto a thin rectangle in Bryce 5, making it a 2D object in a 3D scene.

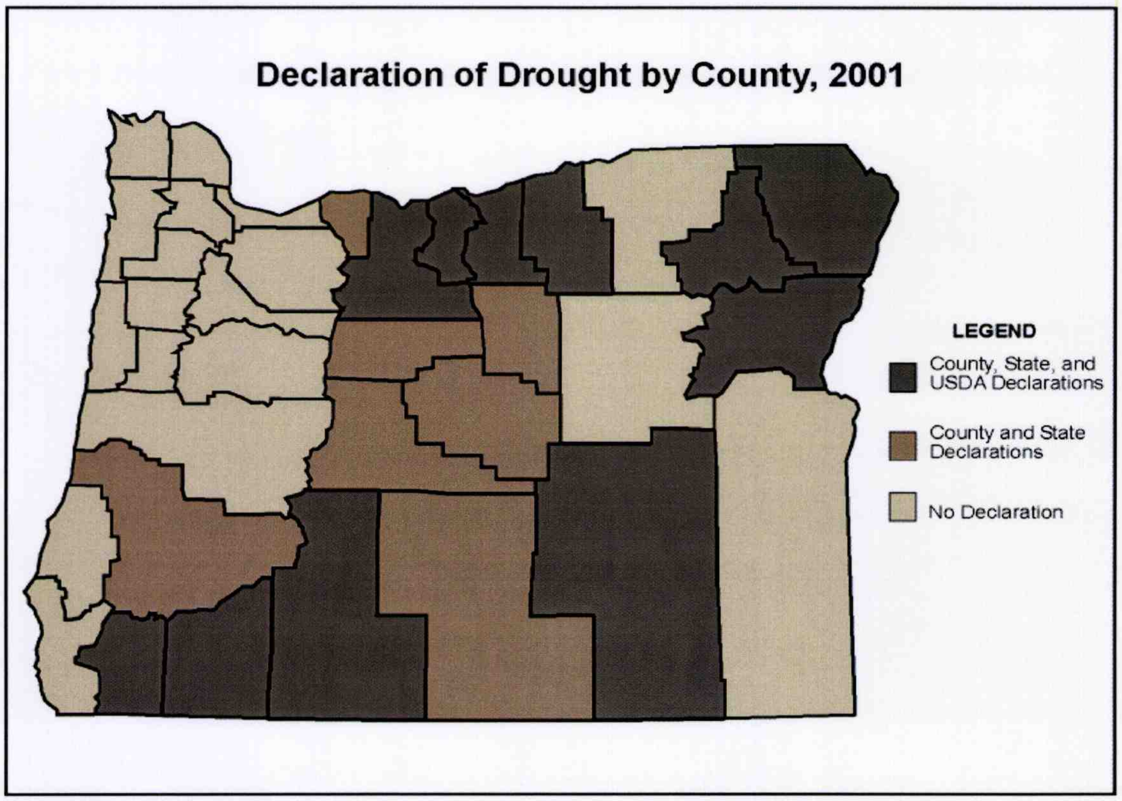

Figure 2. Declaration of Drought.

The second information layer, precipitation, was much more time consuming to research and develop. The initial data were acquired from the National Oceanic and Atmospheric Administration (NOAA). The Climatological Data Annual Summary of Oregon 2001 provided the annual recorded precipitation for over two hundred rain gauge stations across the state. October through November of 2000 was also added into this study, and the corresponding months of 2001 were dropped. This was done in order to temporally synchronize the data with Oregon's water year, which will be discussed later in the Surface and Ground Water section. Only stations with an adequate number of recordings to provide an annual summary were used, resulting in the selection of seventy-six rain gauges. These figures were placed into an Excel spreadsheet along with the corresponding latitude and longitude coordinates of the rain gauge stations. These coordinates were transformed from degrees/minutes/seconds to decimal degrees within the spreadsheet. This table is found in **Appendix A**.

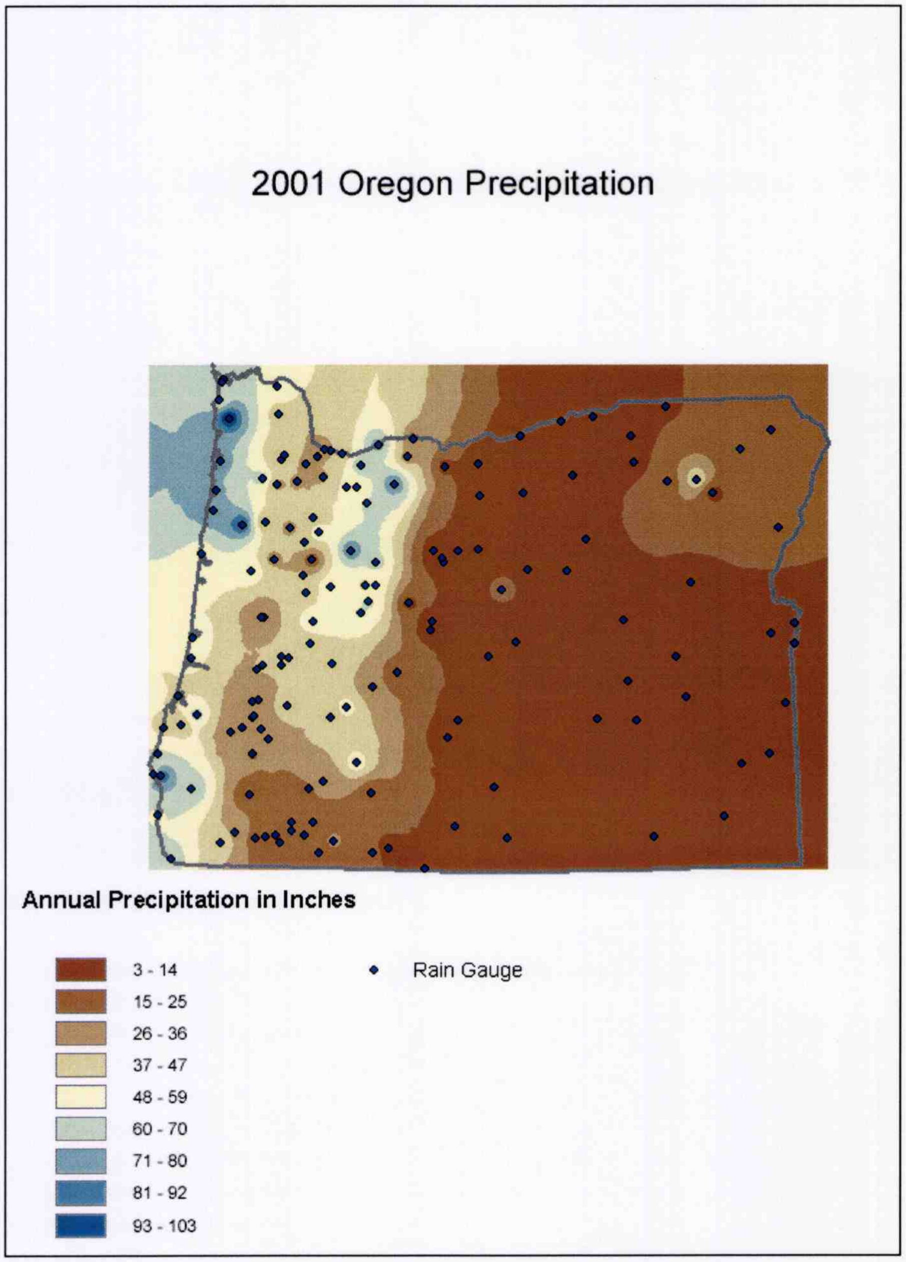

Figure 3. 2001 Oregon Precipitation.

This spreadsheet was then placed into ArcGIS 8 as a database (.dbf) file, and displayed. **Figure 3** shows the locations of the rain gauges used in this project. In order to conceptualize the data across the entire state as a continuous surface spatial interpolation was performed. Each precipitation data point was examined in the spatial analyst extension of ArcGIS. These data points were interpolated to a raster grid using the inverse distance weighting method. The resulting data layer was displayed using a brown to green color progression, brown representing the areas that received the least amount of precipitation in 2001; green representing areas that received the most **(Figure 3)**. A Triangulated Irregular Network (TIN) was also created in ArcGIS's 3D analyst extension **(Figure 4)**.

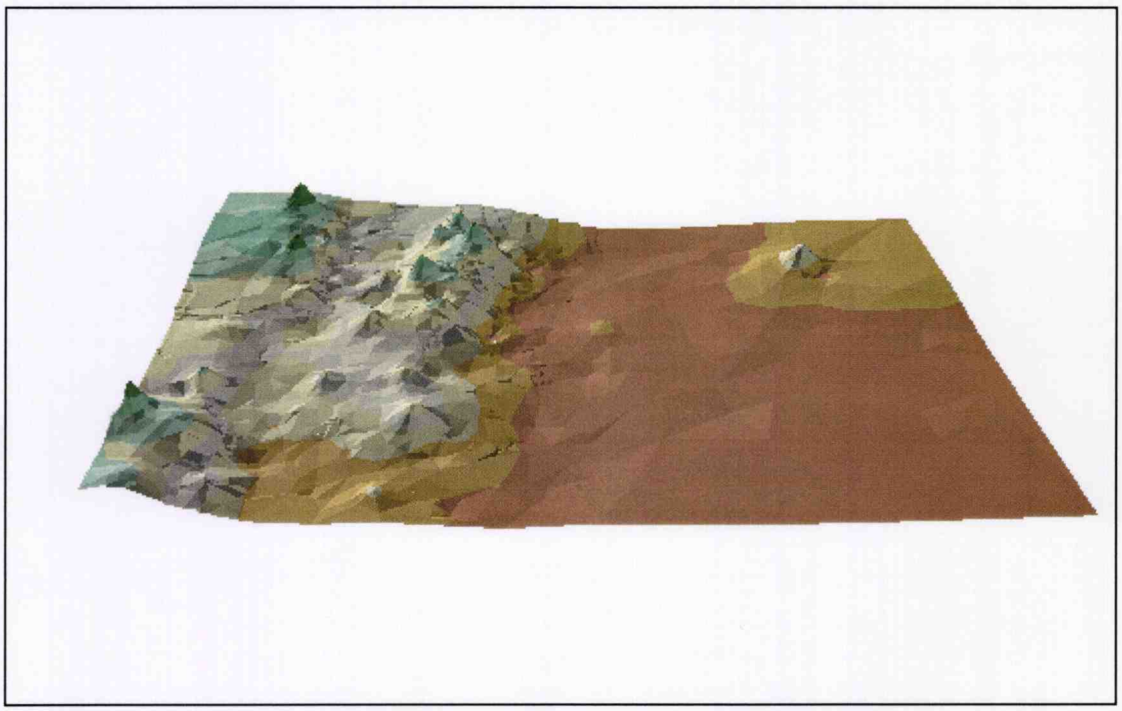

Figure 4. TIN of Precipitation in Oregon, 2001.

Next came the task of importing this precipitation relief into the program Bryce 5. Bryce 5 does not support TINs, therefore another method of creating a relief surface was used. First, the map of precipitation generated in ArcGIS was recolored using a grayscale range, seen in **Figure 5**. This new image was then exported as a .tiff file and opened in Adobe Photoshop 6 in order to resize and crop it, in preparation for use in Bryce 5.

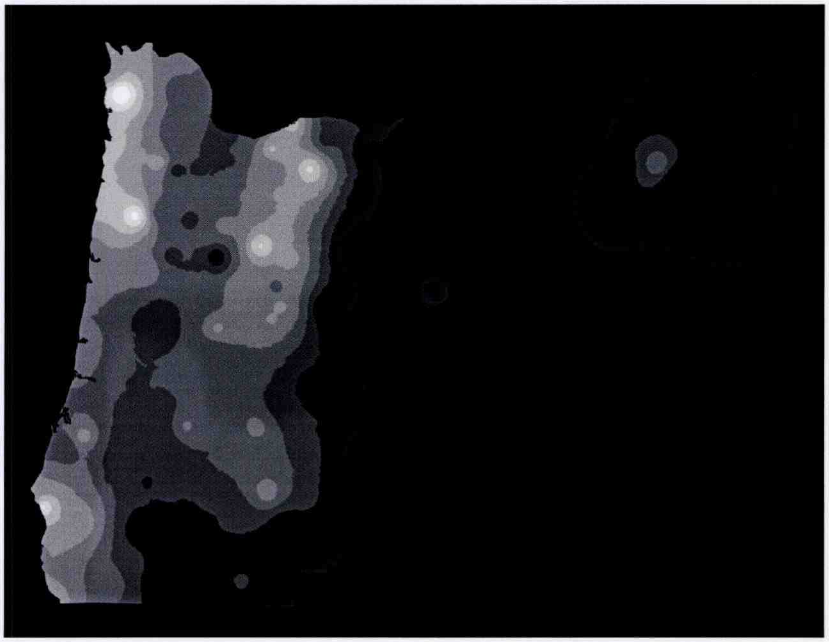

Figure 5. Grayscale Version of Precipitation in Oregon.

Bryce 5 contains a feature that can create a relief surface from any grayscale image. This relief surface can then be manipulated to either increase or decrease the amount relief exaggeration desired. (**Figure 6**) All objects in Bryce 5 are created in a wire frame environment. This allows the user to quickly create and manipulate 3D objects and terrains before performing the time consuming task of rendering the image. The real power of Bryce 5 is its ability to display terrains and objects using a very wide variety of materials and textures. Hundreds of predefined materials and textures are available. A small sample is seen in **Figure 7** and **Figure 8**. Given the vast options available to display the precipitation relief surface, much trial and error was used to develop suitable ways of displaying this information in conjunction with the other measures of drought. A final version was not chosen unit all three variables (precipitation, surface water, and county drought declarations) were initially displayed in Bryce 5. This final version will be addressed later.

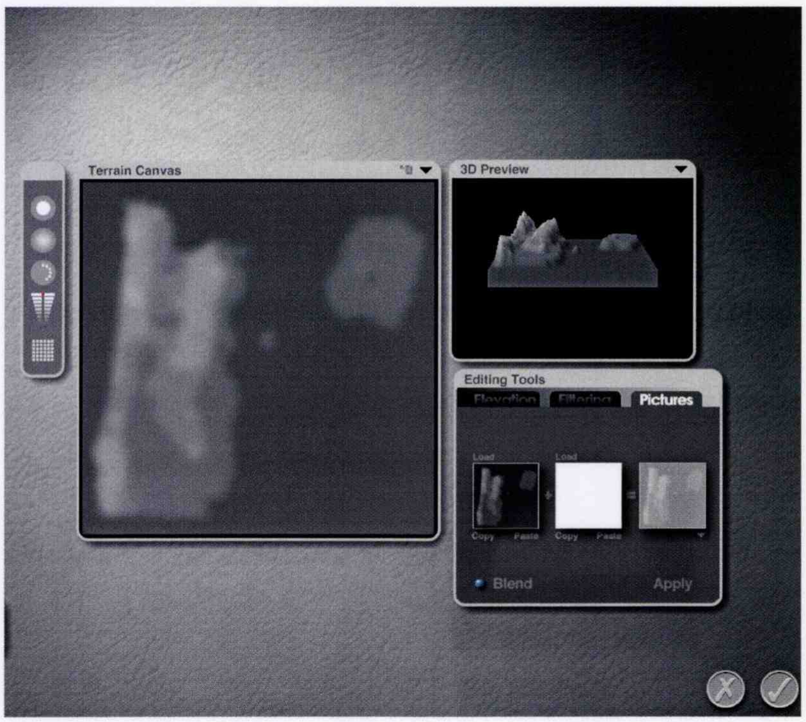

Figure 6. Bryce 5 Relief Interpretation of Grayscale Image.

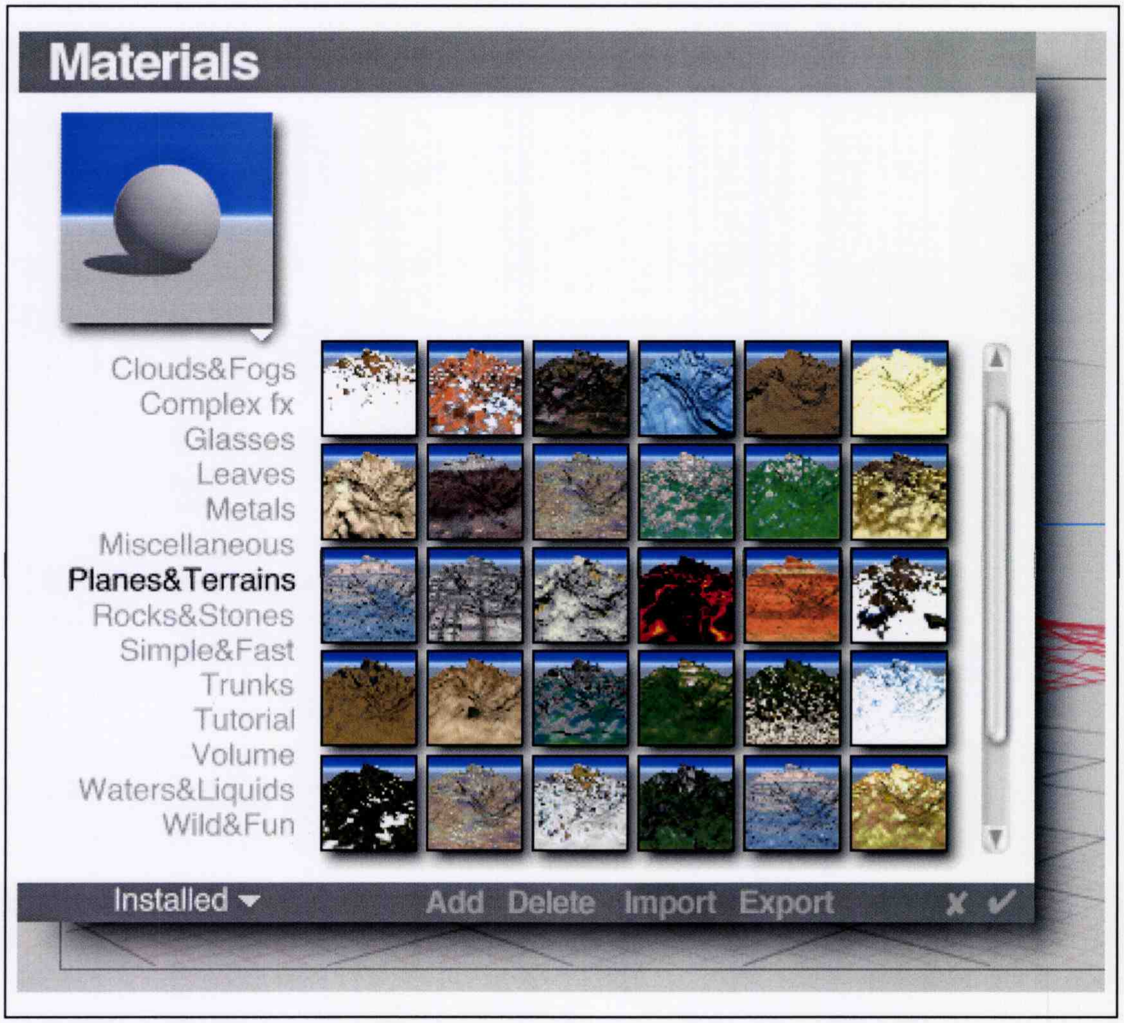

Figure 7. Bryce 5 "Planes & Terrains" Materials.

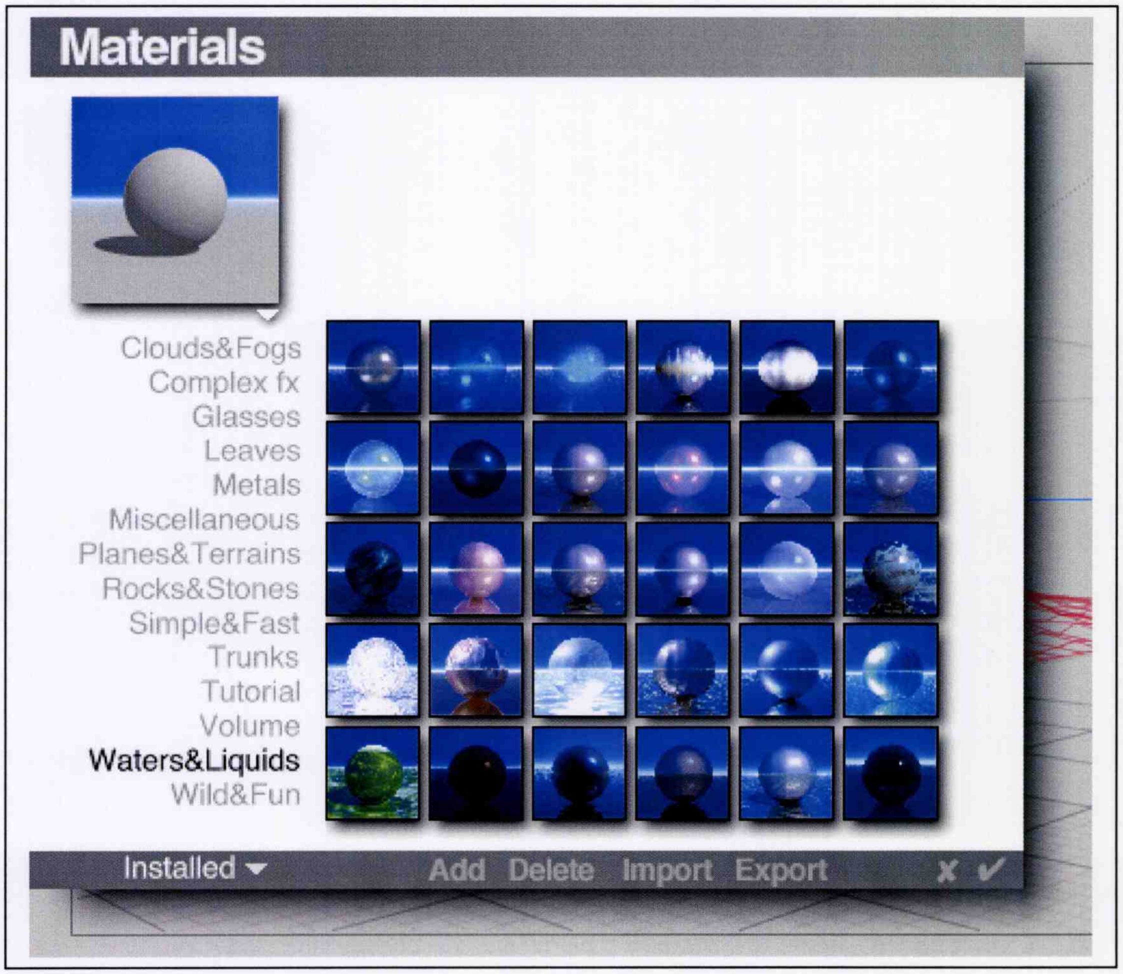

Figure 8. Bryce 5 "Waters & Liquids" Materials.

The third variable, surface water, was then researched and quantified. The U.S. Geological Survey, Water Resources Data, Oregon Water Year 2001, provided the surface water data. A water year is different than a calendar year. For the state of Oregon, the water year for 2001 began October 1st, 2000 and ended September 30th, 2001. For water resource data purposes, these dates are chosen because October 1st is an average date when precipitation for the state typically begins for the wet fall and winter seasons. The water year then terminates at the end of the dry summer months the following year. This allows water data to be scrutinized throughout its entire yearly cycle. Also, the amount of precipitation the state receives during the fall months often will directly dictate which regions will most likely have an excess or deficit of water the following year.

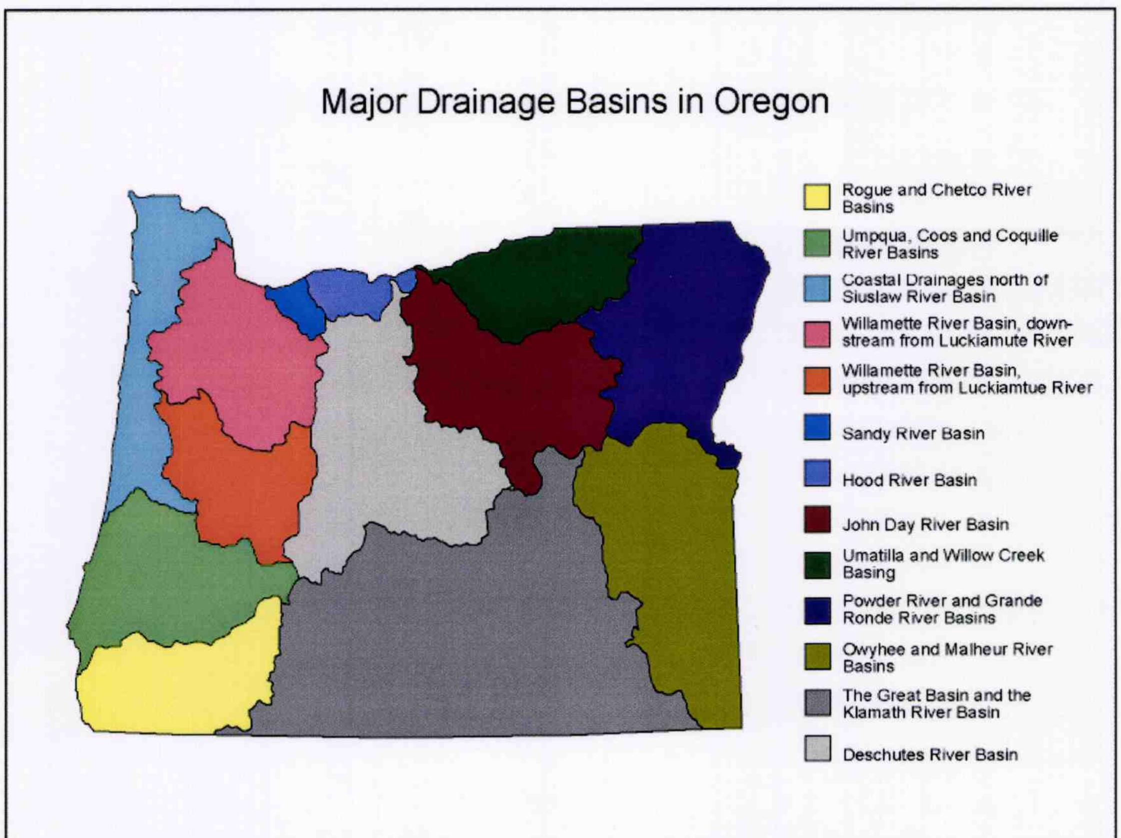

Figure 9. Major Drainage Basins in Oregon.

The water resources data contain surface water measurements pertaining to the thirteen major drainage basins in Oregon. (**Figure 9**) Each major basin contains anywhere from three to thirty-two streamgaging stations, depending on the size and number of rivers present. First, the average annual discharge in cubic feet per second recorded at each of these stations was entered into a spreadsheet. Some of these stations only have discharge records dating back four years, while others have records stretching back to the late 1800s. The average streamgaging station dates back roughly sixty years. The discharge in cubic feet per second recorded at all stations was then totaled for each major basin, providing an estimate of the amount of surface water to be expected each year. Next, the actual annual discharge in cubic feet per second recorded at each station for the water year of 2001 was entered into the spreadsheet. These figures were also totaled per major basin. The result was a concise table of average and actual discharge for each major basin in the 2001 water year (**Appendix B**).

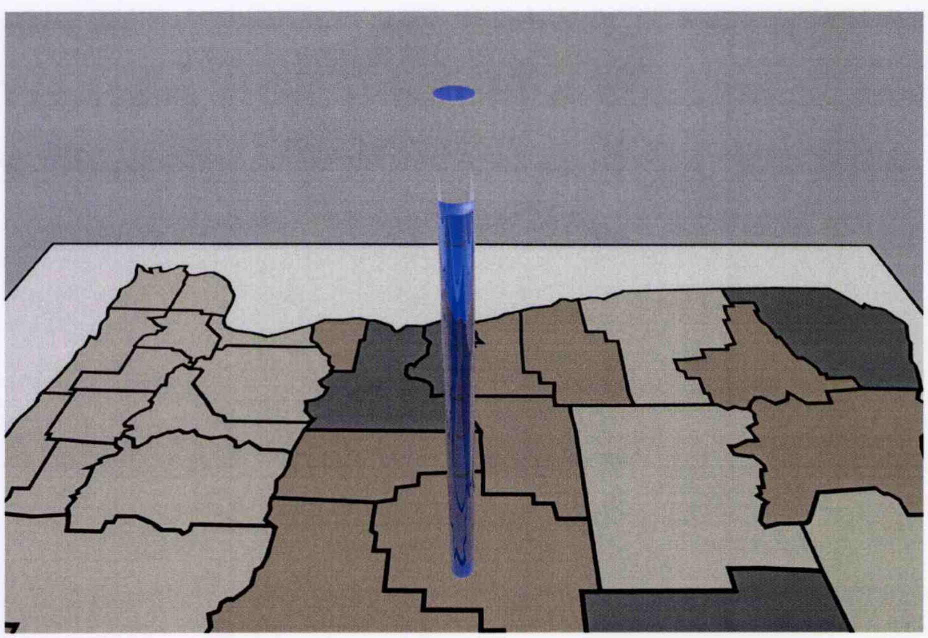

Figure 10. Surface Water Cylinder.

A glass cylinder represents the average surface water. The actual surface water is represented within this glass cylinder using a material resembling water. The result is a glass cylinder that appears to be "filling up" with water, depending on the amount surface water present in each basin (**Figure 10**). Bryce 5 allows objects such as these cylinders to be modified numerically. With a particular cylinder selected, an object attribute dialog box may be opened (**Figure 11**). At the bottom of this box are XYZ options for the size of each cylinder. The XZ numbers remain constant, whereas the Y was modified according to the data from the surface water spreadsheet. The total discharge in cubic feet per second in each basin, numbering in the tens of thousands, was proportionally scaled down into figures that can be easily modified in Bryce 5. For example, the annual (2001) and historic means in cubic feet per second for the Deschutes Basin (13378.6 and 15669.6 respectively) were scaled down 400 percent to 33.45 and 39.18. These numbers were entered into their corresponding cylinders as the Y figure in the attributes dialog box, resulting in a representative symbol of average and actual discharge for each basin.

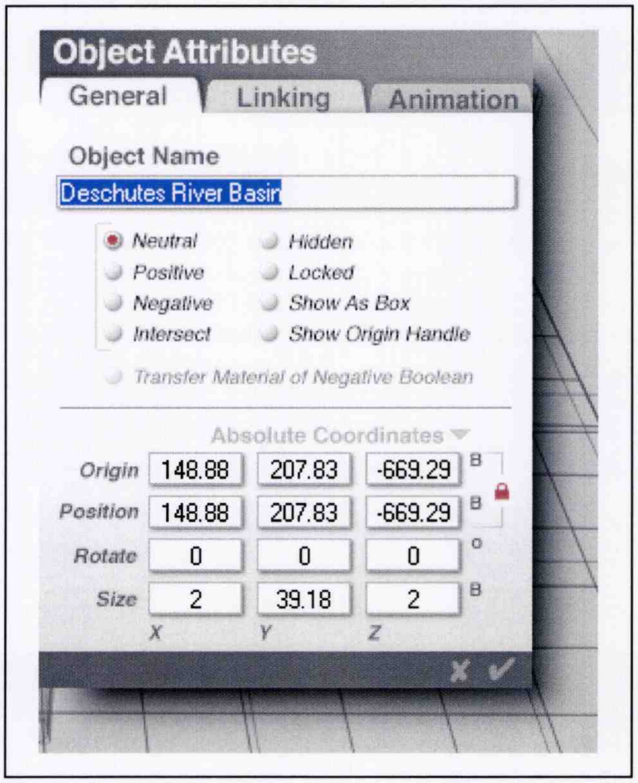

Figure 11. Bryce 5 Objects Attributes.

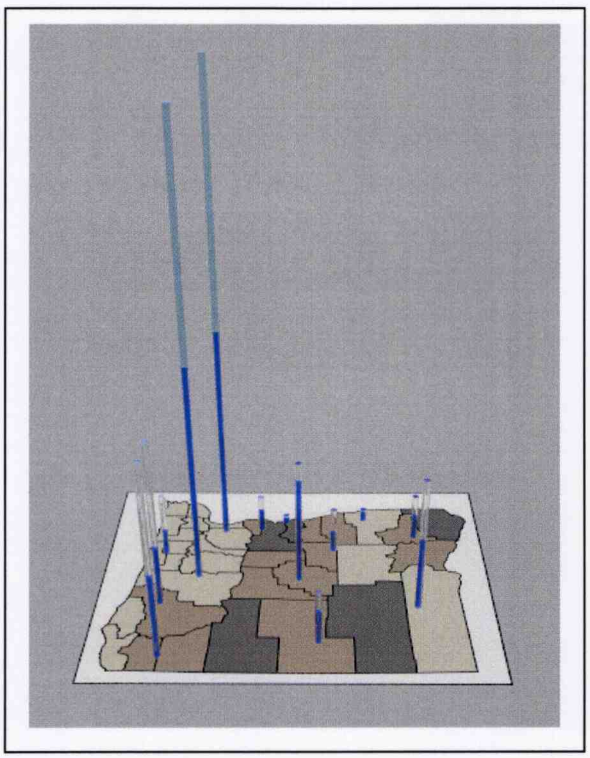

Figure 12. All Cylinders Using the Same Diameter.

The two basins in the Willamette Valley presented a quantitative challenge. If the same diameter for all other major basing in Oregon were used for these two cylinders, a problem arises. The discharge volume is so large in the Willamette Valley, that their corresponding cylinders would dwarf all others in the state (See **Figure 12**). In order to display these cylinders, the entire map would need to be reduced, decreasing overall clarity. Instead, the diameters (XZ) of these two cylinders were increased proportionally by the amount that the height (Y) was decreased. The resulting cylinder retains the same volume, but is more compact and easier to place on the map. The final step was to place these thirteen cylinders on the base map. A base map of the major water basins was mapped onto the same thin rectangle used for the original county declaration map originally was. The cylinders were then placed in central locations in each basin (**Figure 13** and **14**), and were adjusted slightly so that all would be visible in an oblique 3D perspective. The basin map was then removed and the county map was returned.

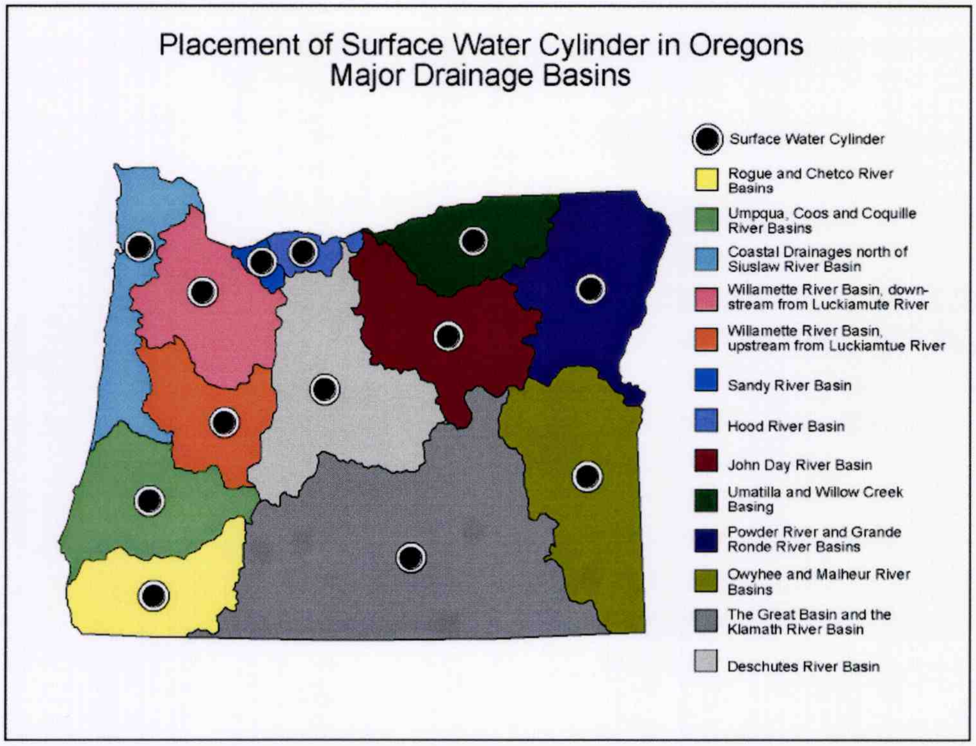

Figure 13. Placement of Surface Water Cylinders.

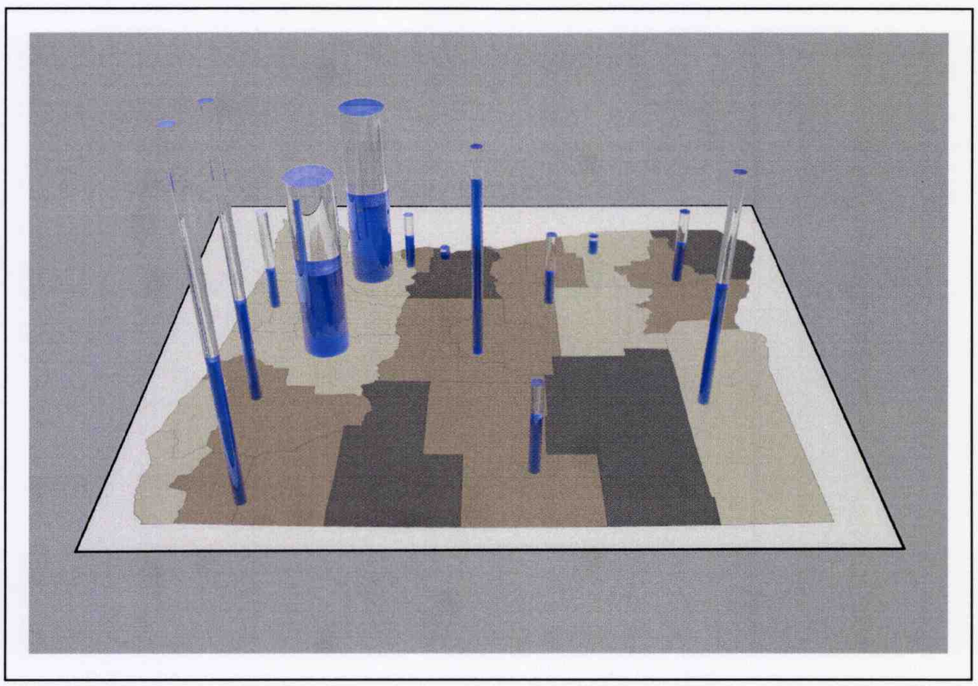

Figure 14. Surface Water Cylinders in Bryce 5.

To represent ground water, a separate scene was prepared in Bryce 5. Five small maps were created in Freehand 9 showing the location of the five wells monitored annually by the USGS. Again, the average water level of each well (measured in feet below the land surface) was compared against readings from 2001. A rock wall material was chosen to represent the average water level, and a water material was selected to represent the actual level recorded in 2001. Unlike surface water, 2001 ground water levels in some monitoring sites exceeded average levels. In these particular sites, the cylinder that represents water appears to extrude from rock wall material **(Figure 15)**.

Figure 15. Ground Water Wells.

With the surface water cylinders mapped onto the base map of drought declaration per county, the final step was to add the precipitation information. This step was by far the most experimental. The first option was to map the county base map onto the precipitation relief. This resulted a superb clarity, but made it impossible to quantify precipitation levels. Several water and glass materials were mapped onto the relief, but again the surface could not be quantified. Finally, isolines were created on the original inverse distance weighted map in ArcGIS 8 and draped over the solid precipitation relief surface. The relief surface was again mapped with a variety of glass and water materials. But combined with the contour lines, clarity was sacrificed. A final iteration involved draping the county base map back onto the precipitation relief, and then adding the isolines. This helped improve the overall clarity of the map while at the same time enabled the quantification of all variables. This map was imported into Freehand 9 for final text, legend, and title placement. It appears as **Appendix C**.

DISCUSSION

Thematic maps, like any work of art, are not conceptualized and created in exactly two steps. In order to thematically represent drought using an advanced graphic package such as Bryce 5, much trial and error occurred. The following portfolio contains the various methods of combining the precipitation relief, isolines, surface and ground water cylinders, and county declaration data, complete with advantages and disadvantages each iteration provides.

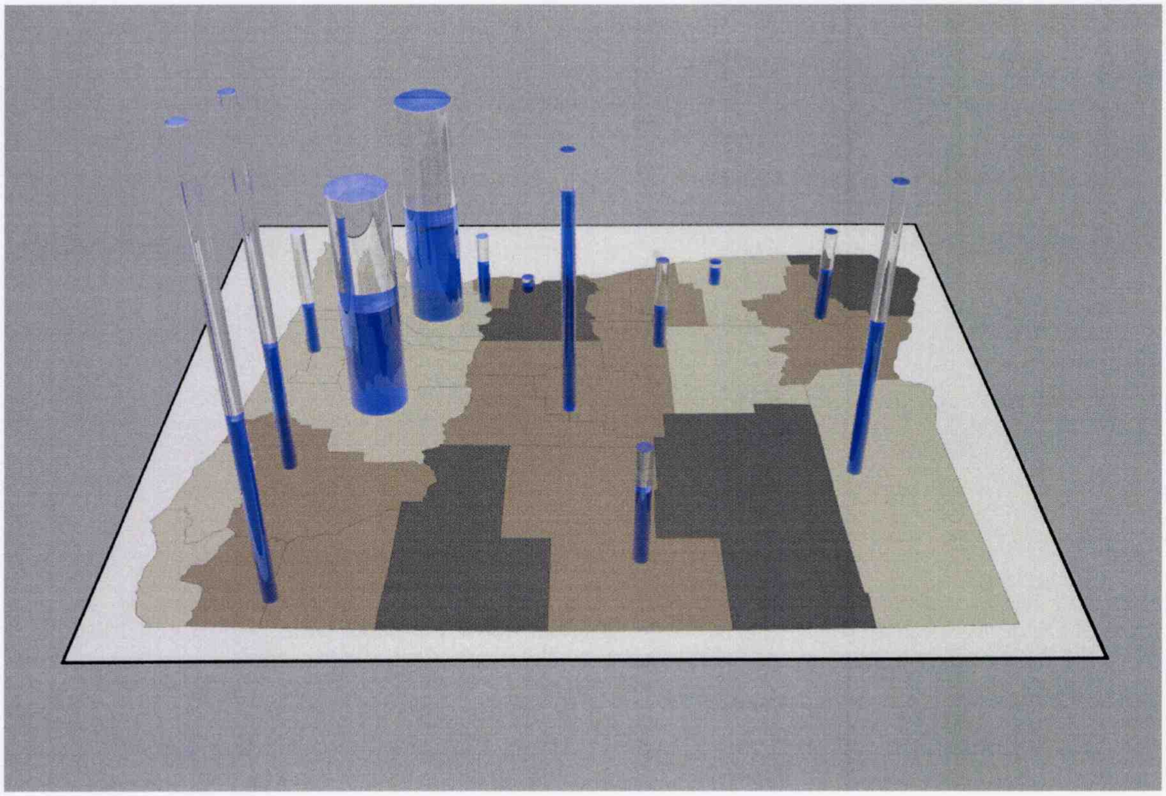

Figure 16. No precipitation relief added.

The cylinders quantifying surface water are placed directly onto the thematic map of drought declaration by county in Oregon, 2001. The precipitation relief surface is not added.

Advantage: Highest level of clarity possible for county declaration data.

Disadvantage: Loss of precipitation data.

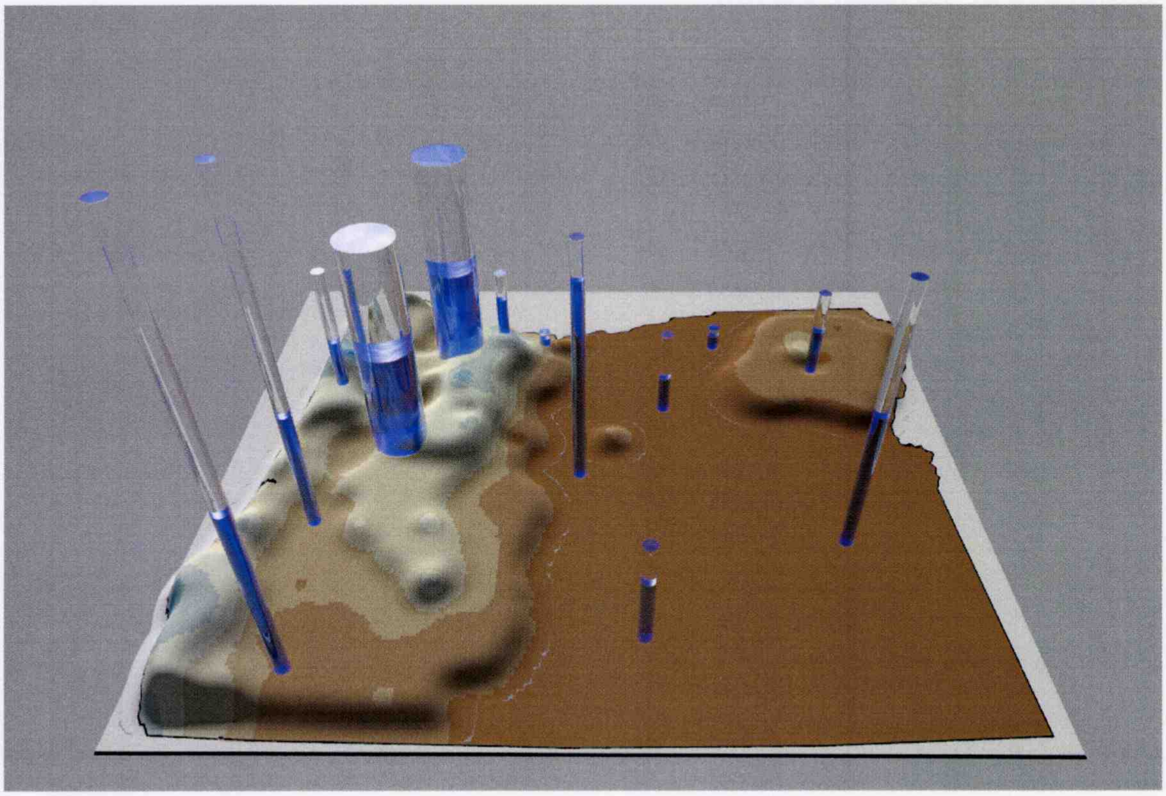

Figure 17. Precipitation theme draped over its own relief.

The original inverse distance weighted theme of precipitation, generated in ArcGIS 8 and exported as a .tiff file is mapped onto the relief surface created in Bryce 5 from the same data.

Advantage: Highest level of clarity possible for precipitation relief.

Disadvantage: Loss of county drought declaration data.

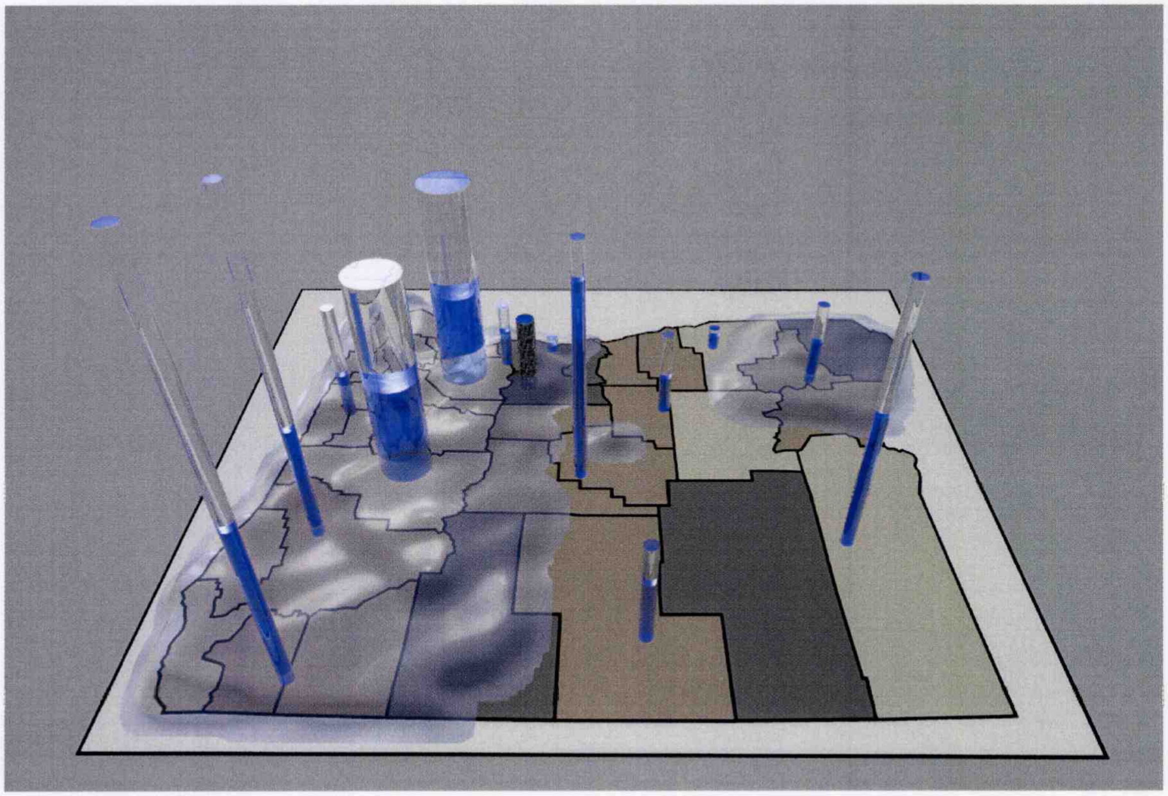

Figure 18. "Bright bubble" material mapped onto precipitation relief, well added.

A semi-translucent material is used to represent precipitation. Surface water cylinders are seen emerging from the water, having been placed flush against the county base map. Also, a single well representing ground water data appears near Hood River County.

Advantage: This material appears to intrinsically represent water, informing the viewer immediately of its nature.

Disadvantage: County data on the base map are partially obscured. Precipitation data are not quantified. Ground water data (the well) are difficult to see. The map is now appearing to look too "busy", even with the remaining four ground water data wells yet to be added.

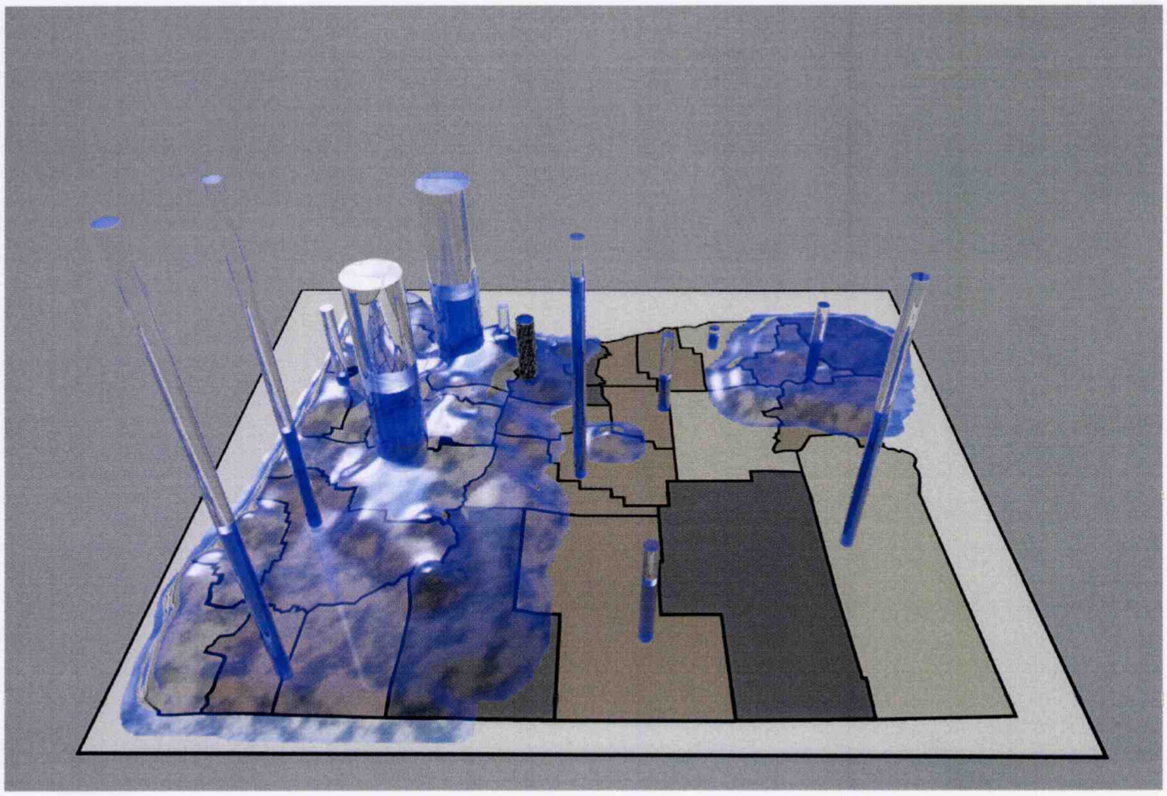

Figure 19. "Dirty glass" material mapped onto precipitation relief.

The "dirty glass" material appears much more dynamic and the 3D illusion of the precipitation relief is very satisfying. Again, the cylinders are emerging from the base map itself through the glass material.

Advantage: Precipitation appears solid, almost quantifiable.

Disadvantages: The darker material used here is now severely obscuring the county data underneath. The solid nature of this material also obscures the surface water cylinders in Hood River and Multnomah County. Also, the precipitation data are not quantified.

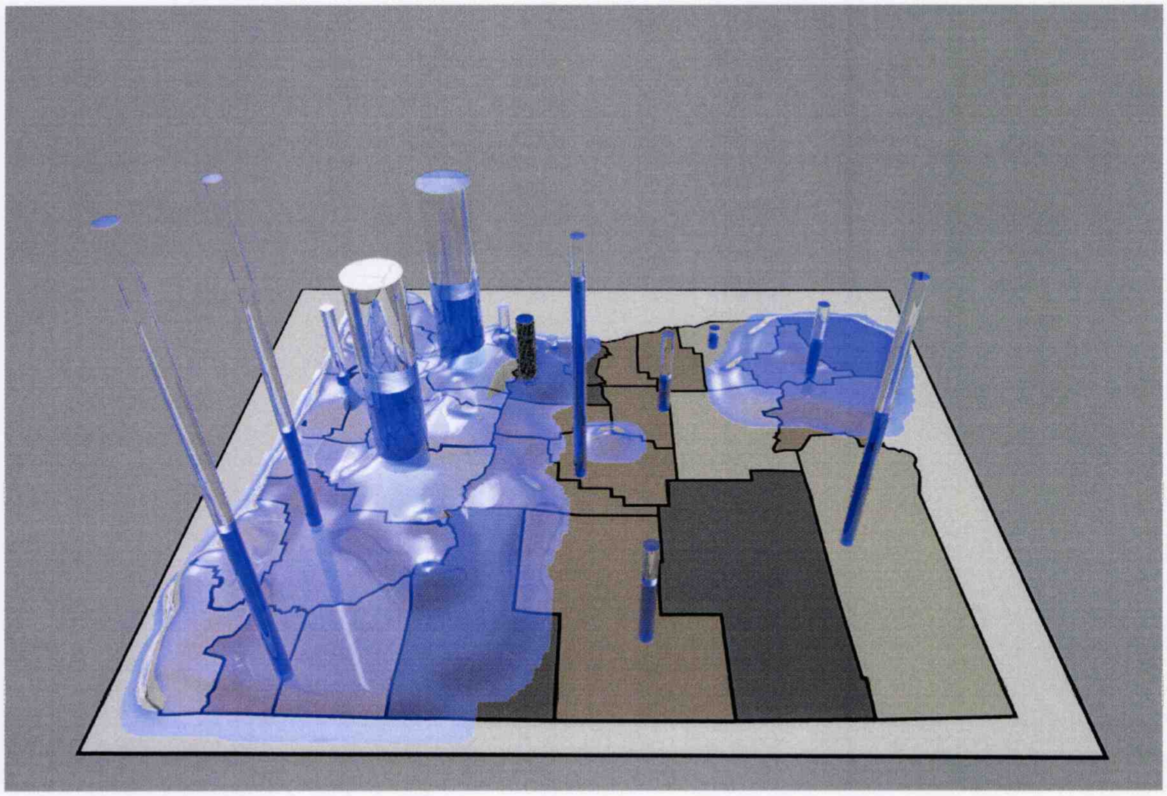

Figure 20. "Oasis" material mapped onto precipitation relief.

This is another material that is very pleasing to the eye. The precipitation relief appears to be glowing, with a high level of reflectivity present.

Advantage: Intrinsic representation of water.

Disadvantages: Shorter surface water cylinders in the northern part of the map obscured. County data partially obscured. Precipitation data are not quantified.

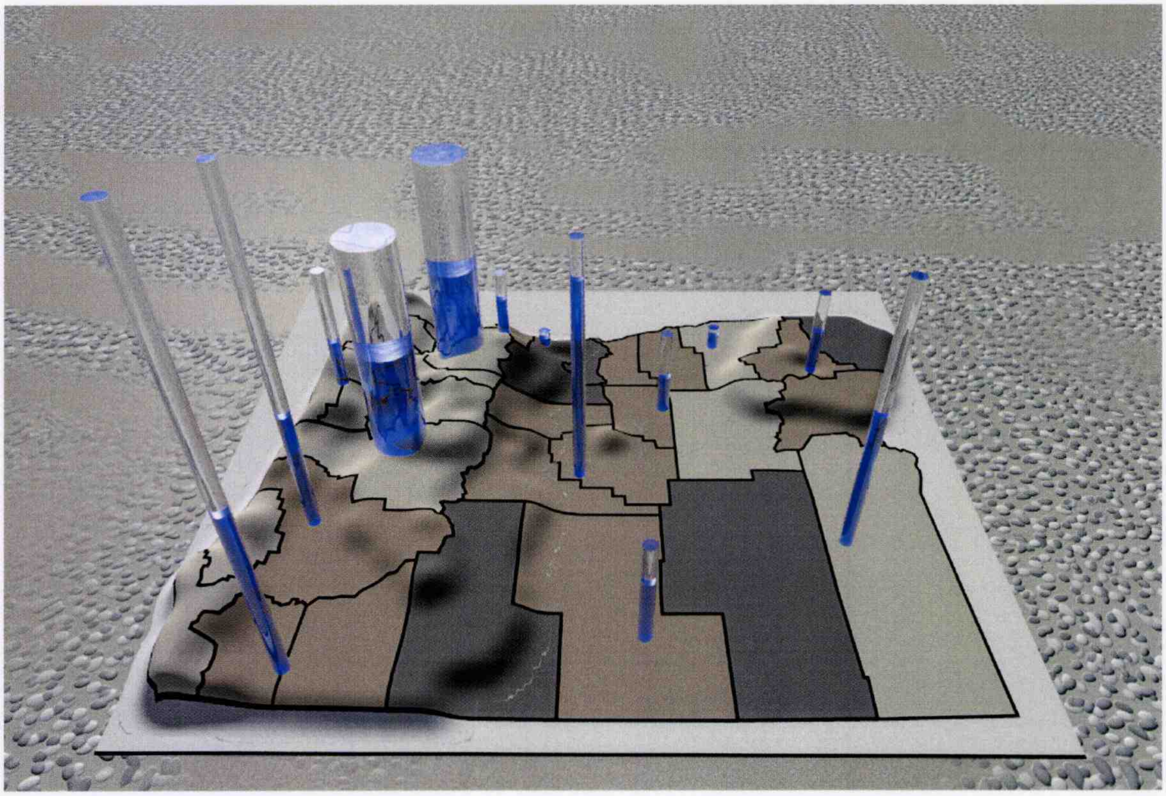

Figure 21. County data draped over precipitation relief.

In a departure from the previous maps, this one began with the precipitation relief being placed onto a thin rectangle in Bryce 5. The base map of drought declaration per county was then draped over this relief and the surface water cylinders added. Due to the opaque nature of this relief style, the cylinders were placed on the relief instead of being flush against the underlying rectangle. Ground water wells were removed. It was decided to display the ground water data as a separate feature.

Advantages: the precipitation relief does not obscure the county data.

Disadvantages: County shapes are distorted. Precipitation data are not quantified.

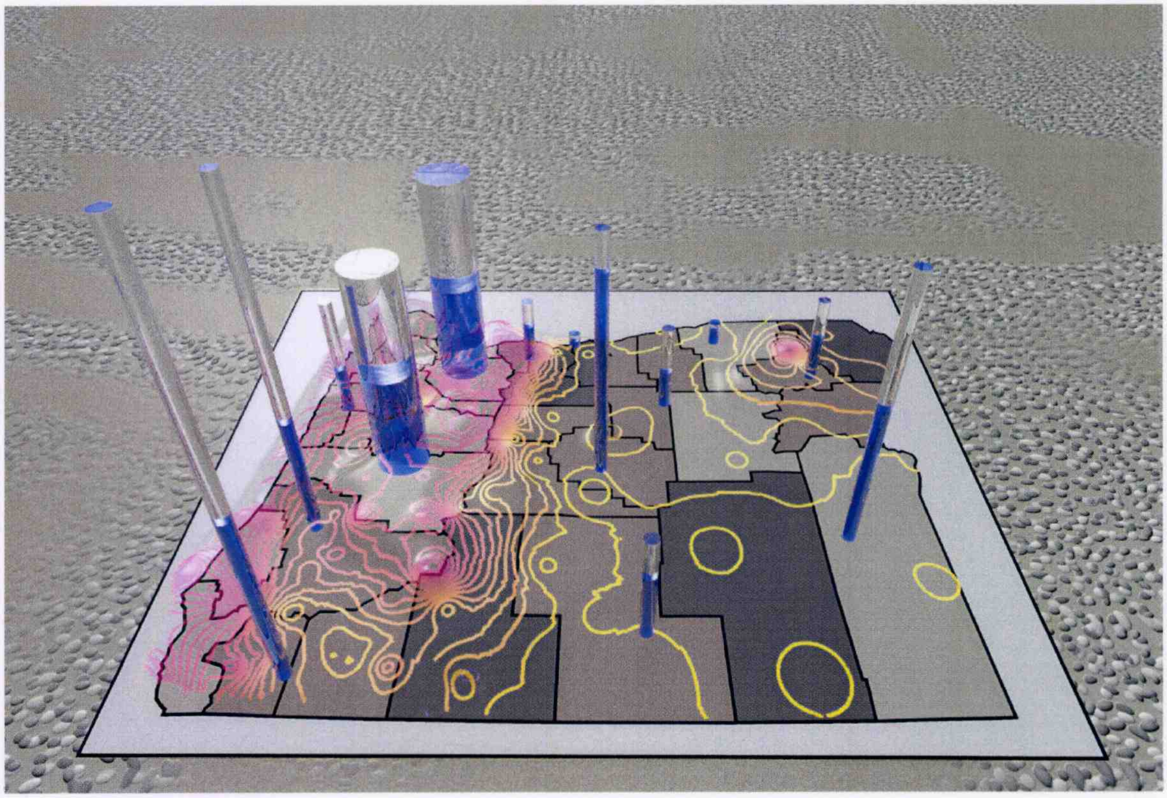

Figure 22. Precipitation isolines draped over glass relief.

In another departure, it was decided to experiment with the addition of isolines onto the precipitation relief. First, ArcGIS spatial analyst was used to create color isolines on top on the original inverse distance weighted precipitation layer. All other layers were then turned off, allowing the image of just the isolines with a white background to be exported as a high-resolution .tiff file. This image was imported into Photoshop 6 where a duplicate image of the isolines was created with a black background instead of white. This will later serve as an alpha channel. Both these images were then imported into Bryce 5. This allowed the program to read the color isolines from the first image, and delete the black areas from the second image (the alpha channel). A highly translucent glass material was mapped onto the precipitation relief. This will serve as a backdrop for the isolines, giving them a more solid appearance. This relief was then duplicated in place. The duplicate was raised very slightly and mapped with the isolines.

Advantages: Quantified precipitation relief in the form of color isolines.

Disadvantages: County data slightly obscured from overlying glass relief.

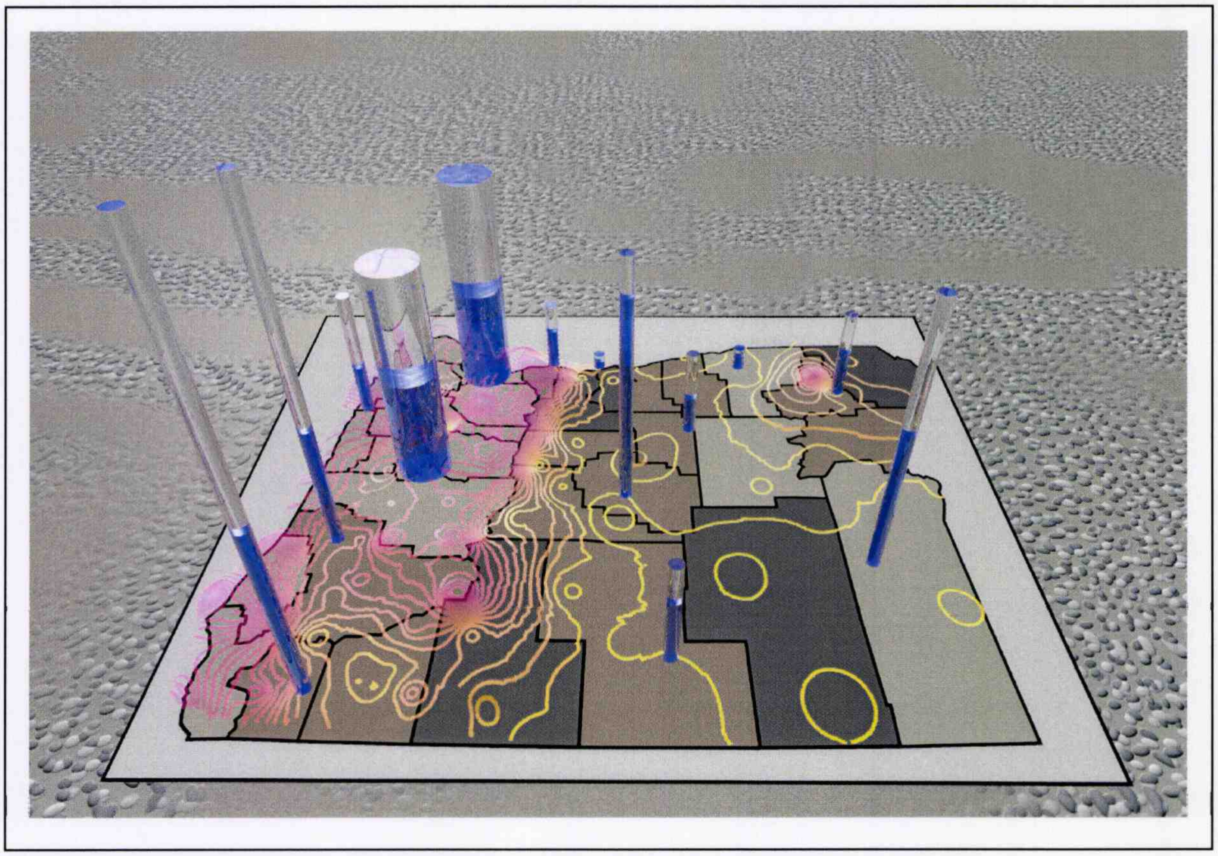

Figure 23. Precipitation isolines draped over an invisible surface.

This iteration is identical to the previous one with two exceptions. First, the glass relief was deleted, making the isolines less 3D in appearance, but allowing the viewer to see the underlying county data more clearly. Second, the surface water cylinders were raised so that they appear to be resting on top of the precipitation isolines.

Advantages: Quantified precipitation data, clear view of county data, raised surface water data (cylinders) contribute to the overall 3D appearance.

Disadvantages. Isolines appear less 3D.

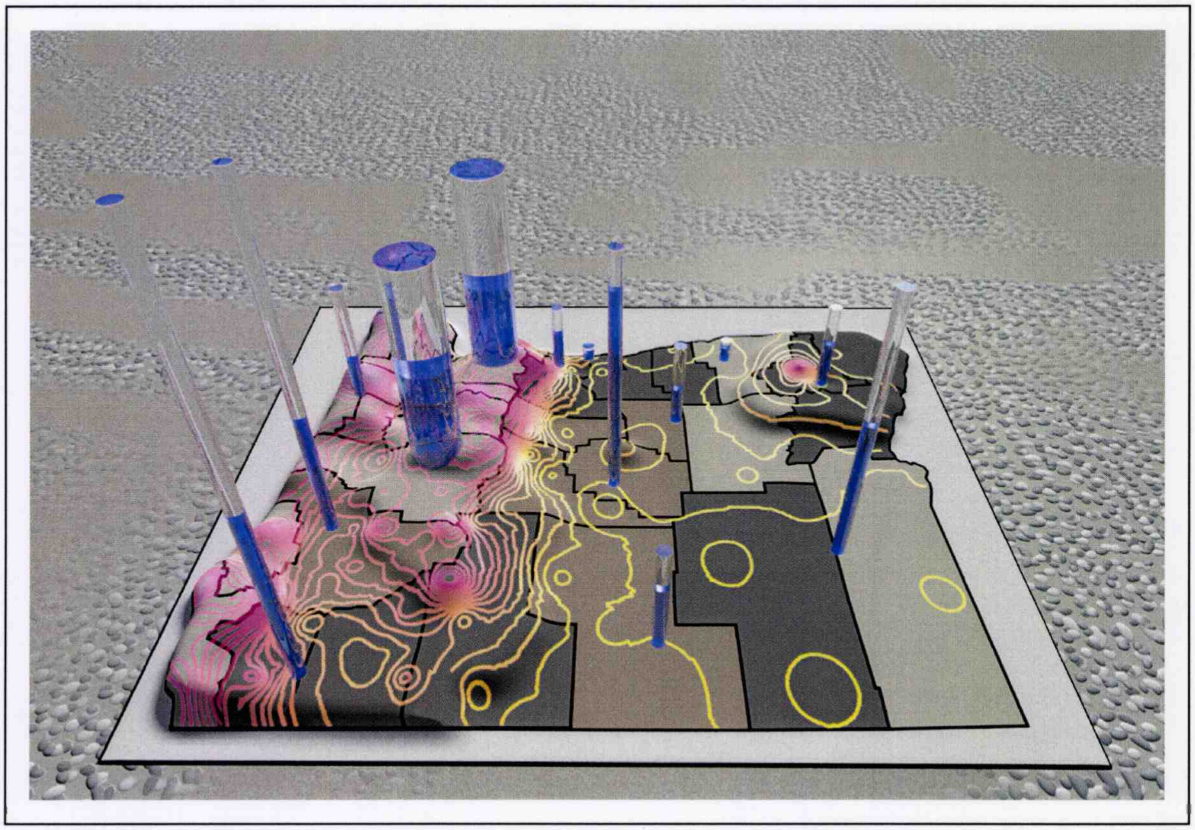

Figure 24. Precipitation isolines draped over county base map, which in turn is draped over precipitation relief.

This final and most complex iteration involved the repetitive draping of various data layers. First, the precipitation relief was placed flush against the base slab. Then the county drought declaration map was draped over this relief. Although this slightly distorts the area of the counties, they are still immediately recognizable. Next the initial relief was duplicated and raised slightly above the draped county map. This relief was made 100% transparent, thus rendering it invisible. Finally, the precipitation isolines were draped over this invisible relief, allowing the viewer to still clearly see the counties underneath. This appealing iteration was chosen as the one to be finalized. It was exported into Freehand 9 to be augmented with text, labels, and legends. It appears as **Appendix C**.

CONCLUSION

Three spatial data sources (drought declaration per county, annual precipitation, and annual surface and ground water levels) in conjunction with the advanced graphic design software Bryce 5 were used in this multivariate thematic mapping study to visualize the Oregon drought of 2001. The methods outlined in this study represent innovative ways of cartographically expressing drought that combines meteorological, hydrologic, and socio-political factors.

Several areas of this study may be further refined before an ideal picture of drought is possible. First, including data quantifying the surface water level of aquifers, lakes and reservoirs would enhance the overall picture of drought in the state of Oregon. Given a diversified weather event such as drought, the amount of data that may be included is seemingly endless. In addition to water body levels, agricultural, soil moisture, and evaporation data may also be included.

This study illustrates that drought should not be dissected in a way that misrepresents the natural phenomena as a whole. By combining both natural and anthropogenic influences, it is possible to produce a more conceptual thematic map of drought. With rapid advancement in cartographic tools such as 3D graphic programs and multimedia packages, there is no reason to keep thematic mapping constrained to simple forms of visualization. By using the processes in this study, a communication tool may be produced that is powerful enough to elicit public interest in drought and in turn instigate appropriate planning and response.

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FIGURES

Figure 1: Wilhite, Donald, 1997, "Improving Drought Management in the West," National Technical Information Services, Springfield Virginia.

Figure 2: Oregon State Drought, Updated Plan, January, 2002, "Drought Assistance Available from State Agencies,"

Figure 3: Drought Mitigation Center, Updated September 30th, 1998, "Impacts of Drought," http://enso.unl.edu/ndmc/impacts.htm.

Appendix A. Precipitation Data

Latitude of Rain Gauge	Longitude of Rain Gauge	Name of Rain Gauge	Annual Precipitation Recorded in Inches	Departure from Normal in Inches
45.72	120.2	ARLINGTON	7.15	-1.79
44.75	120.72	ASHWOOD 2 NE	11.27	-1.62
42.22	122.72	ASHLAND	14.68	-4.52
44.4	123.75	ALSEA F H FALL CREEK	73.45	-18.43
46.15	123.88	ASTORIA AP PORT OF R	60.46	-5.94
43.15	124.4	BANDON 2 NNE	43.49	-15.4
42.03	124.25	BROOKINGS 2 SE	66.12	-6.49
45.2	123.9	CLOVERDALE	70.45	-13.59
42.4	124.42	GOLD BEACH RANGER STN	57.97	-22.42
44.93	124.1	HONEYMAN STATE PARK	57.25	-19.2
42.92	124.45	LANGLOIS #2	59.26	-15.62
44.65	124.05	NEWPORT	54	-17.93
43.42	124.25	NORTH BEND FCWOS	49.73	-13.57
45.45	123.87	TILLAMOOK 1 W	73.35	-13.27
45.63	121.95	BONNEVILLE DAM	75.39	0.46
44.4	122.48	CASCADIA	57.82	-4.77
46.1	123.12	CLATSKANIE	51.92	-5.3
44.63	123.18	CORVALLIS STATE UNIV	33.55	-9.15
44.52	123.45	CORVALLIS WATER BUREAU	58.47	-7.95
43.8	123.05	COTTAGE GROVE 1 NNE	37.01	-8.54
43.72	123.05	COTTAGE GROVE DAM	39.39	-8.74
44.95	123.3	DALLAS 2 NE	37.6	-10.77
45.48	123.12	DILLEY 1 S	37.52	-7.27
43.78	122.97	DORENA DAM	37.43	-9.23
45.27	122.32	ESTACADA 2 SE	49.97	-9.31
44.13	123.22	EUGENE MAHLON SWEET FL R	27.7	-21.67
45.52	123.1	FOREST GROVE	42.71	-1.12
45.32	123.35	HASKINS DAM	65	-8.52
45.45	122.15	HEADWORKS PTLD WTR BUR	71.36	-8.13
44.35	122.78	HOLLEY	42.54	-8.11
44.1	122.68	LEABURG 1 SW	61.02	-3.13
43.92	122.77	LOOKOUT POINT DAM	40.31	-4.63
45.35	122.6	OREGON CITY	34.92	-12.04
45.58	122.6	PORTLAND INTL AIRPORT	30.44	-5.86
45.3	122.92	REX 1 S	35.59	-5.9
45.87	122.82	ST HELENS RFD	35.68	-8.23
44.9	123	SALEM AP MCNARY FIELD R	33.67	-5.49
45	122.77	SILVERTON	38.7	-8.8
44.78	122.82	STAYTON	40.76	-10.85
45.55	122.38	TROUTDALE	41.83	-3.13
42.18	123.68	CAVE JUNCTION 1 WNW	46.16	-13.48
43.67	123.2	DRAIN	36.82	-9.32
42.13	122.55	GREEN SPRINGS POWER PL	20.28	-2.16
43.37	122.97	IDLEYLD PARK 4 NE	49.67	-13.33
42.3	122.87	MEDFORD EXPERIMENT STN	14.8	-5.98
42.38	122.87	MEDFORD WSO AP	15.01	-3.85
42.73	122.52	PROSPECT 2 SW	32.28	-8.76
43.13	123.62	RESTON	32.43	-18.11
42.22	123.05	RUCH	20.37	-5.05
42.23	123.28	WILLIAMS 1 NW	22.68	-9.82
43.28	123.35	WINCHESTER	27.78	-6.59
44.28	122.03	BELKNAP SPRINGS 8 N	61.88	-12.35
44.72	122.25	DETROIT DAM	81.68	-4.91
44.18	122.12	MC KENZIE BRIDGE R S	59.74	-7.67
43.75	122.45	OAKRIDGE FISH HATCHERY	38.6	-6.86
45.13	122.07	THREE LYNX	59.35	-12.8
43.68	121.68	WICKIUP DAM	19.02	-2.24
45.23	120.18	CONDON	11.33	-2.72
45.45	121.13	DUFUR	11.22	-1.29
45.68	121.52	HOOD RIVER EXP STN	26.42	-4.4
45.95	118.42	MILTON FREEWATER	13.41	-0.92
45.48	120.72	MORO	8.32	-2.8
45.7	118.85	PENDLETON MUNICIPAL AP R	10.42	-1.6
45.48	118.83	PILOT ROCK 1 SE	10.26	-3.48
43.95	120.22	BARNES STATION	11.12	-1.02
43.6	118.57	BURNS MUNICIPAL AP R	8.33	-1.63
44.73	120.97	LOWER HAY CREEK	10	-0.73
44.63	121.13	MADRAS	8.26	-2.16
44.73	121.25	PELTON DAM	8.95	-1.1
44.88	117.12	HALFWAY	19.66	-1.87
45.32	118.07	LA GRANDE	13.16	-4.28
44.82	119.42	MONUMENT	11.43	-2.18
45.2	117.88	UNION EXPERIMENT STN	10.68	-3.1
42.95	117.33	DANNER	9.87	-2.56
43.37	117.12	ROCKVILLE	7.12	-4.56
42.87	117.65	ROME 2 NW	7.64	-0.64

Appenix B. Surface Discharge per Basin in Cubic Feet per Second.

The figures in each column represent the data collected at a particular river or stream in each given basin.

Total annual mean (2001)

Total annual mean (historic)

Discharge, Cubic Feet Per Second

The Great Basin and the Klamath River Basin

Annual Mean (2001)	82.8	124	36.8	291	697	925	979	1242	**4377.6**
Annual Mean (Historic)	127	185	74.2	586	1048	1282	1647	1830	**6779.2**
Highest Annual Mean	273	468	93.4	1395	2187	2200	3582	3024	13222.4
Lowest Annual Mean	49.1	7.84	36.8	199	483	547	340	564	2226.74

Owyhee and Malheur River Basins

Annual Mean (2001)	414	112	8285	133	83.9	94.6	**9122.5**
Annual Mean (Historic)	950	417	14400	191	145	297	**16400**
Highest Annual Mean	3400	2991	26260	566	335	535	34087
Lowest Annual Mean	162	22.3	7365	46.8	54.6	87	7737.7

Powder River, Snake River Main Stem, Pine Creek, Imnaha River, and Grande Ronde River Basins

Annual Mean (2001)	10950	244	93	179	121	90.7	107	70.8	65.6	395	263	1617	**14196.1**
Annual Mean (Historic)	20600	513	138	283	192	178	182	115	112	685	456	3075	**26529**
Highest Annual Mean	36560	897	227	358	288	235	251	178	149	952	713	5253	46061
Lowest Annual Mean	9746	184	93	179	90.9	90.7	107	46.2	65.6	395	189	1136	12322.4

Umatilla and Willow Creek Basins

Annual Mean (2001)	158	129	19	2.65	343	4.62	39.3	372	11.5	0.7	11.1	**1090.87**
Annual Mean (Historic)	227	203	29.3	3.14	568	5.66	43	477	22.2	2.75	22.3	**1603.35**
Highest Annual Mean	415	352	35.5	4.95	777	10.6	72.5	1026	44.3	6.23	45.5	2789.58
Lowest Annual Mean	114	66.2	19	1.47	343	2.08	10.7	77.5	6.84	0.24	7.79	648.82

John Day River Basin

Annual Mean (2001)	111	129	615	877	916	**2648**
Annual Mean (Historic)	203	257	1300	1944	2080	**5784**
Highest Annual Mean	393	538	2608	4116	4724	12379
Lowest Annual Mean	73.5	85.1	441	619	608	1826.6

Deschutes River Basin

Annual Mean (2001)	883	1263	68	57.6	1429	4207	45.4	62	122	53.2	45.4	297	4846	**13378.6**
Annual Mean (Historic)	928	1562	94.3	85.6	1498	4708	78.9	114	166	69.4	86.4	448	5831	**15669.6**
Highest Annual Mean	1461	2196	137	142	1949	5980	136	187	242	114	166	786	7969	21465
Lowest Annual Mean	677	1250	66.8	54	1167	3558	43.2	62	107	46.5	41.6	246	4290	11609.1

Columbia River between the Deschutes River and Boneville Dam in the Hood River Basin

Annual Mean (2001)	541	**541**
Annual Mean (Historic)	1018	**1018**
Highest Annual Mean	1664	1664
Lowest Annual Mean	465	465

Columbia River between Boneville Dam and confluence with the Willamette River and Sandy River Basin

Annual Mean (2001)	785	17.4	35.6	251	19.3	44.3	40.7	74.9	89.1	1334	11.6	**2702.9**
Annual Mean (Historic)	1350	26.6	58.1	410	34.8	73.3	65.9	112	144	2287	17	**4578.7**
Highest Annual Mean	2018	37.5	88.1	643	53.5	121	105	171	223	3456	22.4	6938.5
Lowest Annual Mean	766	17.4	33.5	249	19.3	44.3	40.7	74.9	87.6	1334	11.6	2678.3

Willamette River Basin upstream from the Luckiamute River

Annual Mean (2001)	1669	1934	57.9	2404	236	583	260	37.1	366	113	53.3	256
Annual Mean (Historic)	2860	3063	115	4146	595	1587	458	89.6	629	251	123	458
Highest Annual Mean	4710	4660	182	6722	1008	2701	688	136	917	404	207	727
Lowest Annual Mean	1416	1392	57.9	1877	233	512	241	37.1	346	106	49.2	192

Annual Mean (2001)	2706	1321	1471	193	5821	55.8	183	221	125	6748	**7969.3**
Annual Mean (Historic)	4098	2641	2918	530	11400	229	480	774	455	14780	**14374.6**
Highest Annual Mean	6014	4550	5034	883	17800	424	907	1517	816	24080	23062
Lowest Annual Mean	2447	1321	1471	164	5233	45.5	183	177	104	5831	6459.2

Willamette River Basin, downstream from the Luckiamute River

Annual Mean (2001)	596	292	48.3	401	2079	391	326	80.3	1674	4.2	4067	281	11190	515
Annual Mean (Historic)	1006	574	110	749	3455	817	653	215	3003	7.57	7816	889	24030	2029
Highest Annual Mean	1506	892	162	1146	5255	1280	1113	318	4666	10.5	12310	1464	37960	2796
Lowest Annual Mean	569	276	48.3	400	1743	359	311	80.3	1407	4.2	3512	230	9792	515

Annual Mean (2001)	0.53	511	18.1	4.83	334	50	130	1.21	19.3	429	286	1106	99.6	1504
Annual Mean (Historic)	2.06	1149	36.9	25.1	801	113	360	3.35	34.8	1442	482	2022	212	2816
Highest Annual Mean	3.1	1822	50.5	48.8	1191	217	695	5.95	56.2	2787	739	3128	335	4407
Lowest Annual Mean	0.53	511	18.1	4.83	334	40.4	104	1.21	19.3	278	286	1062	99.6	1454

Annual Mean (2001)	13.4	21.6	38.7	2.55	**21944.8**
Annual Mean (Historic)	29.1	53.9	80.6	5.72	**45353.57**
Highest Annual Mean	45.4	91.7	137	9.11	70878.5
Lowest Annual Mean	13.4	15.6	38.7	2.55	19246.8

Oregon Coastal Drainages north of the Siuslaw River Basin and in the lower Columbia River

Annual Mean (2001)	1044	495	461	7.65	660	8.28	494	**3169.93**
Annual Mean (Historic)	2673	1178	1077	17.2	1514	24.9	1474	**7958.1**
Highest Annual Mean	4292	1811	1449	29.4	2337	46.7	2541	12506.1
Lowest Annual Mean	1044	495	461	7.65	660	8.28	431	3106.93

Appenix B. Surface Discharge per Basin in Cubic Feet per Second. (Continued)

Umpqua, Coos and Coquille River Basins														
Annual Mean (2001)	317	20	56.6	152	650	42.9	36.6	32.6	36.8	38.8	911	274	175	1710
Annual Mean (Historic)	1027	84.2	257	682	2773	58.7	59.6	19.4	127	94	1476	733	460	3726
Highest Annual Mean	1762	179	499	1221	5567	90.7	125	52	247	155	2080	1253	805	6116
Lowest Annual Mean	268	20	56.6	152	562	36.9	24.1	5.85	36.8	38.8	897	239	158	1639
Annual Mean (2001)	125	2557	283	207	**4453.3**									
Annual Mean (Historic)	449	7404	782	539	**11576.9**									
Highest Annual Mean	905	13360	1374	759	20151.7									
Lowest Annual Mean	125	2321	237	207	4134.05									
Rogue and Chetco River Basins														
Annual Mean (2001)	957	27	74.7	1319	38.4	1402	31.3	37	1499	1609	127	0.87	139	160
Annual Mean (Historic)	1471	78.4	257	2080	217	2428	96.2	115	2913	3294	435	5.17	542	747
Highest Annual Mean	2053	224	501	3224	438	4012	226	304	5098	5840	829	15.1	1072	1546
Lowest Annual Mean	957	17.6	74.7	1314	38.4	1381	22	8.42	1491	1538	127	0.6	139	160
Annual Mean (2001)	2033	307	770	**7421.27**										
Annual Mean (Historic)	5524	1262	2246	**14678.77**										
Highest Annual Mean	10180	2372	3911	25382.1										
Lowest Annual Mean	2033	275	549	7268.72										