GROUND WATER DATA AND POTENTIOMETRIC SURFACE MAPS OF THE MONOCACY WATERSHED MODEL

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for the
Maryland Department of the Environment

May 1989

ICPRB Report 89-5

Interstate Commission on the Potomac River Basin
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ACKNOWLEDGMENTS

This work was performed for the Maryland Department of the Environment under the 205j Grant Program, Memo of Understanding dated April 26, 1989. Elizabeth Casman, Carlton Haywood and Barbara Barritt provided editorial assistance.

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INTRODUCTION

The purpose of this study is to provide information to enhance the ground water component of the water quality model of the Monocacy River Basin currently being constructed by MDE and ICPRB. Ground water is an important component of the Monocacy model, not only for its hydrologic role, but also in terms of water quality and land use associations. This report provides support material to the Monocacy modeling effort in terms of parameter selection, flow network determination, and specification of initial ground water nutrient concentrations. The Monocacy modeling framework is HSPF. HSPF's treatment of ground water movement is adapted for use with large heterogeneous watersheds, so it departs from the more sophisticated theory used with better described systems, in favor of some simplified empirical relationships.

MODELING CONSIDERATIONS

The simulation of outflow from ground water storage in HSPF is conceptualized and simplistic. In HSPF the discharge of an aquifer is proportional to the cross-sectional area and the energy gradient of the flow (from Darcy's law). The cross-sectional area is related to the ground water storage level at the start of a given interval of time. Estimation of the energy gradient is done conceptually by a basic gradient and a variable gradient dependent on past ground water history (i.e. from the previous time step). The simplified equation for ground water outflow is:

$$AGWO=KGW*(1.0+KVARY*GWVS)*AGWS$$

where:

AGWO = active ground water outflow in (inches $interval^{-1}$)
KGW = ground water outflow recession parameter, ($interval^{-1}$)
KVARY = parameter which can make active ground water storage to outflow relation nonlinear ($inches^{-1}$)
GWVS = index to ground water slope (inches)
AGWS = active ground water storage at the start of the interval (inches)

GWVS is the term that represents the dynamic hydraulic gradient and is increased each interval by the inflow to active ground water. HSPF decreases this term by 3% each day (without explanation!). This will then provide a measure of antecedent active ground water inflow. KVARY is included so that ground water recession rates can vary with time, and one of the parameters that will require substantial "tweaking" during calibration of HSPF. The recession parameter KGW is calculated by:

$$KGW=1.0-(AGWRC)^{(DELT60/24.0)}$$

where:
AGWRC = daily recession constant of ground water flow if KVARY or GWVS = 0. That is, the ratio of current discharge to discharge 24 hours earlier
DELT60 = hr $interval^{-1}$

Since this is a highly conceptualized model, the formulae are not truly physically-based deterministic representations of the processes. Thus, measurable aquifer characteristics such as transmissivity and hydraulic head do not enter into the model explicitly. However, a preliminary estimate of the parameter GWVS can be obtained from data. Hydraulic gradients (i.e. ground water slope) can be calculated from measured values of hydraulic heads at observation wells.

A map of the potentiometric surface (i.e. contour map of hydraulic heads) can be created if enough data are available for a drainage basin. This contour map will then provide estimates of hydraulic heads for any location in the basin from which hydraulic gradients can easily be extracted. This can be used as a guide to determine where the gradients are steep and where they are not steep so that the slope index could be better approximated. Potentiometric maps will also provide an overview of the ground water flow directions (i.e. flowlines are perpendicular to equipotential lines). The Monocacy model divides the basin into 37 sub-basins. Subsurface connections between these sub-basins can be determined from these maps as well. (See map in Appendix 1.)

Potentiometric maps were made for all the 16 major creeks which are tributary to the Monocacy.

METHODS

The potentiometric maps were created by digitizing measurements of water levels in wells from published records. This information was then manipulated mathematically (using the SURFER contour drawing software) to create lines of equal water level (i.e. equipotential or potentiometric lines) throughout the basin. The data were screened so that only measurements taken during the months of May through August were used. This helps to eliminate natural seasonal variations in the data.

Data were grouped into one mile square grids. This grid size was chosen to provide a sufficient number of points to cover each individual sub-basin while not being too cumbersome for digitizing. Grouping data has two major limitations:

1. When an individual grid cell contained several wells, their location was specified as the centroid of their locations. Therefore the precision of the spatial locations of the measurements suffers and becomes an "averaged" value for the grid cell. This should not affect the overall potentiometric surface very much at the scale that is being analyzed for each basin.

2. The potentiometric surface should, in general, resemble the surface topography. However, where there is a paucity of data, some topographic features may be lost. For example, areas on top of high peaks are generally not populated, therefore well data are not available at the highest elevations within the basins. If the only data available in an area are in lowlands, the interpolation routine will predict too low water elevations in the adjacent higher elevations. This is not a major problem, except perhaps in the Catoctin Mts., due to the extensive lowlands of the Monocacy valley. Conversely, wells on parallel ridges with no intervening wells may result in interplated water table elevations that are actually above the land surface in the valley. Again, this is not a major problem at the scale of this exercise.

Two plots of the potentiometric data are presented, 2-D contour maps, and 3-D orthographic projections. The 2-D maps are convenient for indicating flow paths, while the 3-D Potentiometric Surfaces are superior for visualizing the potentiometric surface features. "Flowlines" are sketched on the maps. A rule of thumb when interpreting flowlines at this scale is that they will tend to diverge from areas of ground water recharge and converge to areas of ground water discharge.

The transfer of physiographic features from the topographic maps to the potentiometric maps was done by hand. Streams and drainage boundaries are drawn in at their approximate locations.

Water quality information is also presented on a one square mile grid, resulting in the same losses of resolution as with water surface elevation data. The data were quite scarce, and the time frame covered many years. Therefore these data provide only a rough guide to the ground water quality in the area of the measurement because they represent an average value of data spanning many years and covering large areas.

HYDROGEOLOGY

The individual formations underlying the basin are quite complex, and aquifers may extend through several formations at once. Water bearing fractures can hydraulically connect formations and intraformational differences may be as hydrologically significant as interformational differences. The boundaries of aquifers are difficult to identify precisely.

Non-carbonate areas are generally believed to have flashier hydrographs than carbonate areas. This then causes a flatter slope of the recession limb as larger volumes of storage get released.

Low lying areas tend to have more shallow water tables that don't fluctuate as much as upland area water tables. This is important for the seasonal fluctuation of the thickness of the unsaturated zone. Where data were available, these fluctuations are presented in tables for the respective basin.

The major aquifers of the area can be assumed to exist in the top 150 feet of material. This is because the highest percentage of fracturing is found in this layer (see the appendix and Otton, 1980, and Otton & Hilleary, 1979).

Most streams in the Monocacy are areas of ground water discharge (i.e. effluent streams) for the entire year. Streams in the Hagerstown area have been documented as being influent streams, but it seems that this is the exception not the rule. In non-carbonate terrane, discharge into stream channels is usually by seepage through the porous material. In carbonate areas, however, springs can be very significant. The potentiometric maps support the assertion that ground water flows to streams.

Recharge has been estimated to range from about 12-30% of annual precipitation in this area. Flow rates have been estimated to be on the order of tens of feet per day in most of the basin but could be much higher in the limestone areas (Duigon & Dine, 1987)

Topographic highs may indicate areas of greater strength of geologic material, and therefore less fractures may be found there. Also, depth to water is generally greater in the higher elevations than in the lower elevations.

The following report treats each of the major tributaries in detail, presenting potentiometric and water quality data.

BIG PIPE CREEK

HYDROLOGY

The ground water drainage system of Big Pipe Creek corresponds to the surface drainage divide in most of this basin (Figures 1 and 2). The possible exception to this lies in the western part indicated on the map with a "?". At this location the ground water may be part of a larger aquifer that extends beyond the boundaries of the basin. The system flows toward Big Pipe Creek. Averaging data from different wells over different years implies the assumption that the ground water levels remain approximately constant between years for a given season. At the level of resolution used here, this is probably a reasonable assumption as long as there are no extremely large withdrawals.

There was no apparent pattern in depth to water measurements over the basin, however as a rule of thumb the ground water table will be more shallow in valleys (0 - 40 feet to water would be a typical value) and deeper in hills (30 - 70 feet). However, there could be significant variations on a local scale.

Most streams in any humid region are effluent streams (i.e. the ground water discharges to the stream because the hydraulic gradient is toward the stream) for most of the year, but could become influent (i.e. stream discharges to ground water and the hydraulic gradient is toward the ground water) at certain times of the year and at specific stretches. The period used for water level measurements (May-August) in this study is typically a time of high evapotranspiration and lower ground water levels, therefore is the most likely period for Big Pipe Creek to be influent. The flowlines on the map, Figure 1, show the stream to be effluent, strongly suggesting that the stream is effluent throughout the year.

The dots on the map in Figure 1 show the locations of springs. These are local areas of ground water discharge. As previously mentioned, other significant discharge areas are found near the streams - particularly Big Pipe Creek itself (look for converging flow lines). Also, in general, wetlands can be considered discharge areas (however, if there is a confining layer under the area, the wetland may actually be formed by a perched water table and is therefore not a discharge area. Detailed geologic cross sections and localized field data would be necessary to determine the location of discharge areas precisely). There don't appear to be any large confining zones in the Big Pipe Creek basin because the potentiometric surface generally follows topography. Recharge areas are typically found where flowlines diverge and are usually located in topographic highs. Another characteristic of these recharge areas is that they have thick unsaturated zones.

WATER QUALITY

Hilleary & Weigle (1981) listed several wells in the basin where water quality data have been reported. These wells are located on Figure 1 with letters A-J. Corresponding nitrogen and phosphorus data are listed in Table 1. These data are derived from measurements made in 1975. If more than one well was found in the same grid block, an average location is shown on the map and an average value is reported in Table 1 map. Location "H" on the map may be an area of concern. It is in a recharge area for the basin and the nitrogen concentration in the ground water is relatively high. NO_3 nitrogen above 10 mg/l can be a health hazard and NO_2 nitrogen above 5 mg/l can be toxic to fish. Also, total phosphorus levels of 0.01 mg/l or greater promote eutrophication (Fetter, 1980). "H" is just outside the basin but is close enough to suggest possible nutrient problems. Locations "I" and "F" have the highest phosphorus concentrations and are both located fairly close to the streambed where discharge areas are likely to occur.

Table 1. NITROGEN and PHOSPHORUS CONCENTRATIONS BIG PIPE CREEK WELLS

Location	Nitrogen (mg/l)	Total Phosphorus (mg/l-P)	Depth (feet below land)
A	11.0 (NO_3-N)	0.02	51
B	3.0 (NO_2+NO_3)	0.02	40
C	2.7 "	-	30
D	0.01 "	-	65
E	0.7 "	-	55
F	2.3 "	0.04	30
G	0.53 "	-	14
H	6.4 "	0.03	34
I	4.0 "	0.05	40
J	4.4 "	0.03	40

"-" indicates missing data

Figure 1. Potentiometric Surface of Big Pipe Creek Basin

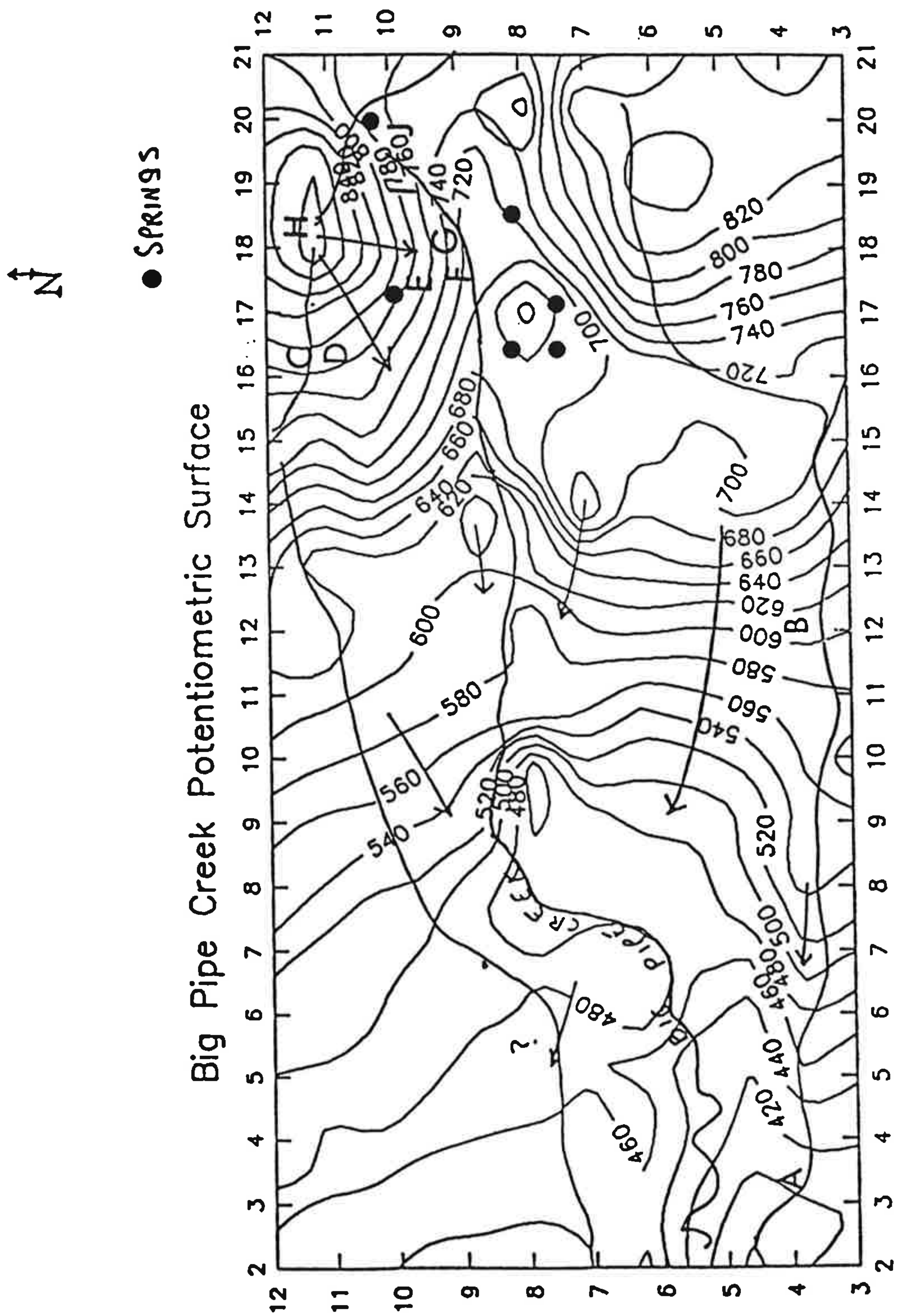
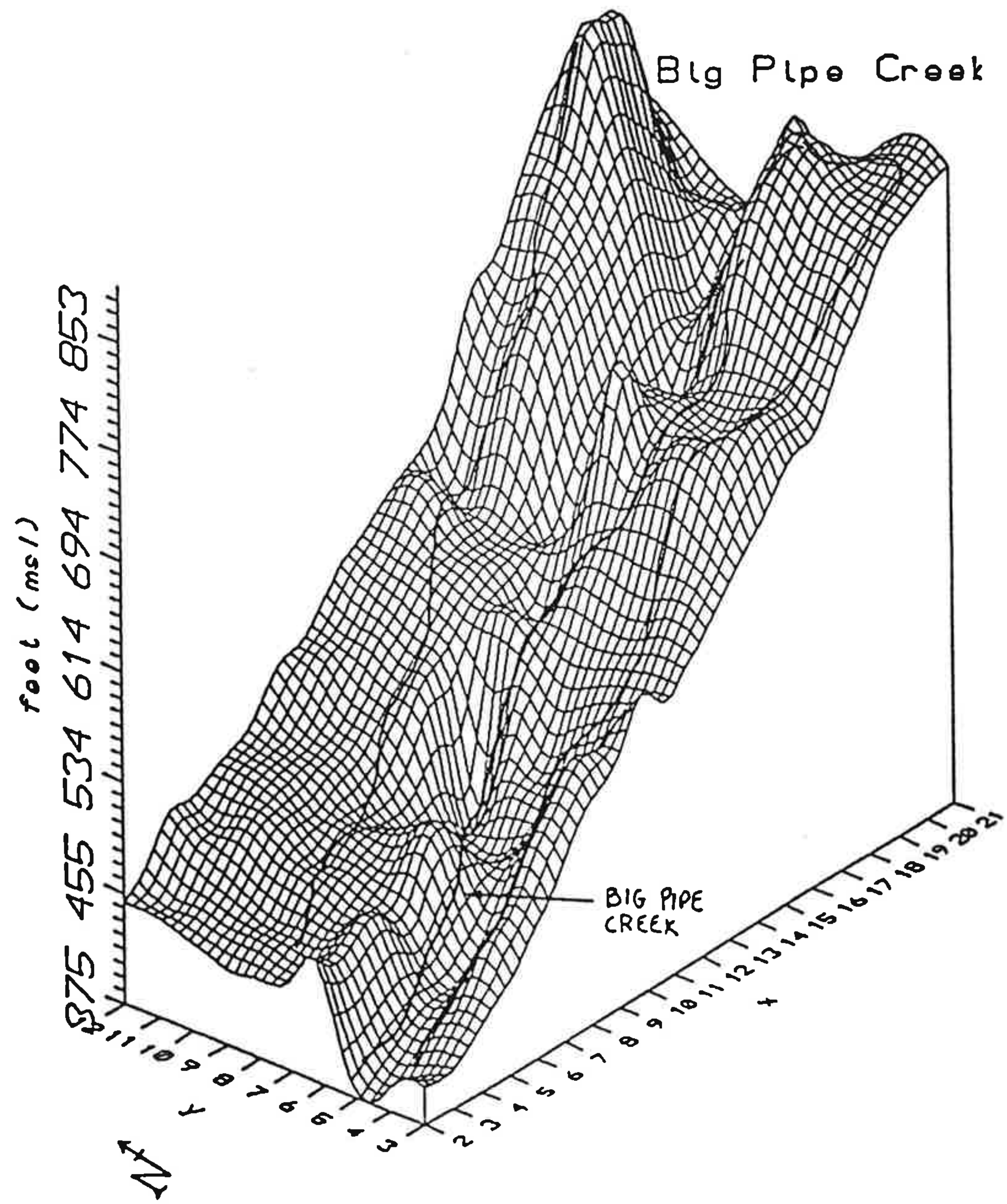


Figure 2. 3-D Potentiometric Surface Map of Big Pipe Creek Basin



LITTLE PIPE CREEK BASIN

HYDROLOGY

The ground water drainage system corresponds to the surface drainage divide in most of this basin (Figures 3 and 4). The possible exception to this lies in the eastern part, indicated on the map with a "?" where ground water from the Linganore Creek sub-basin appears to be flowing into the Little Pipe Creek sub-basin. At this location the ground water may be part of a larger aquifer that extends beyond the boundaries of the basin. The system flows generally toward Big Pipe Creek.

Overall in summer depth to water is in the range 0 - 40 feet. The most shallow measurements can be found in the northwest part, close to where Little and Big Pipe join to form Double Pipe Creek. The water table was within 15 feet in many of these wells and deeper in the hills (i.e. 30-70 feet). The flowlines on the map indicate that the stream is probably effluent throughout the whole length.

The dots on the map indicate springs. These are local areas of ground water discharge. As previously mentioned, other significant discharge areas are found near the streams - particularly Little Pipe Creek itself and near the outfall of the basin. Recharge areas are typically found where flowlines diverge and are usually located in topographic highs. Another characteristic of these recharge areas is that they have thick unsaturated zones.

WATER QUALITY

The Carroll county ground water data report listed several wells in the basin where water quality was measured. These are indicated on Figure 3. Each letter corresponds to the well location, and nitrogen and phosphorus concentrations are listed in Table 2. The data all come from measurements made in 1975, and if more than one well was found in the same area, an average value is reported on the map. It seems that location 'E' on the map may be an area of concern. That area has been identified as a discharge area in the basin and the phosphorus concentration in the ground water seems to be relatively high there.

Table 2. NITROGEN and PHOSPHORUS CONCENTRATIONS LITTLE PIPE CREEK WELLS

Location	Nitrogen (mg/l)		Total Phosphorus (mg/l-P)	Depth (feet below land)
A	2.4	(NO_2+NO_3)	0.01	40
B	2.5	"	0.03	15
C	0.63	"	-	47
D	2.0	"	0.04	-
E	2.3	"	0.01	0(spring)
F	3.3	"	-	45
G	1.8	"	0.03	50
H	0.75	"	-	-

"-" indicates missing data

Nitrogen may not be a major problem but phosphorus seems high. The concentration of phosphorus at the spring (a ground water discharge) seems to be higher than would be caused by natural conditions.

Figure 3. Potentiometric Surface of Little Pipe Creek Basin

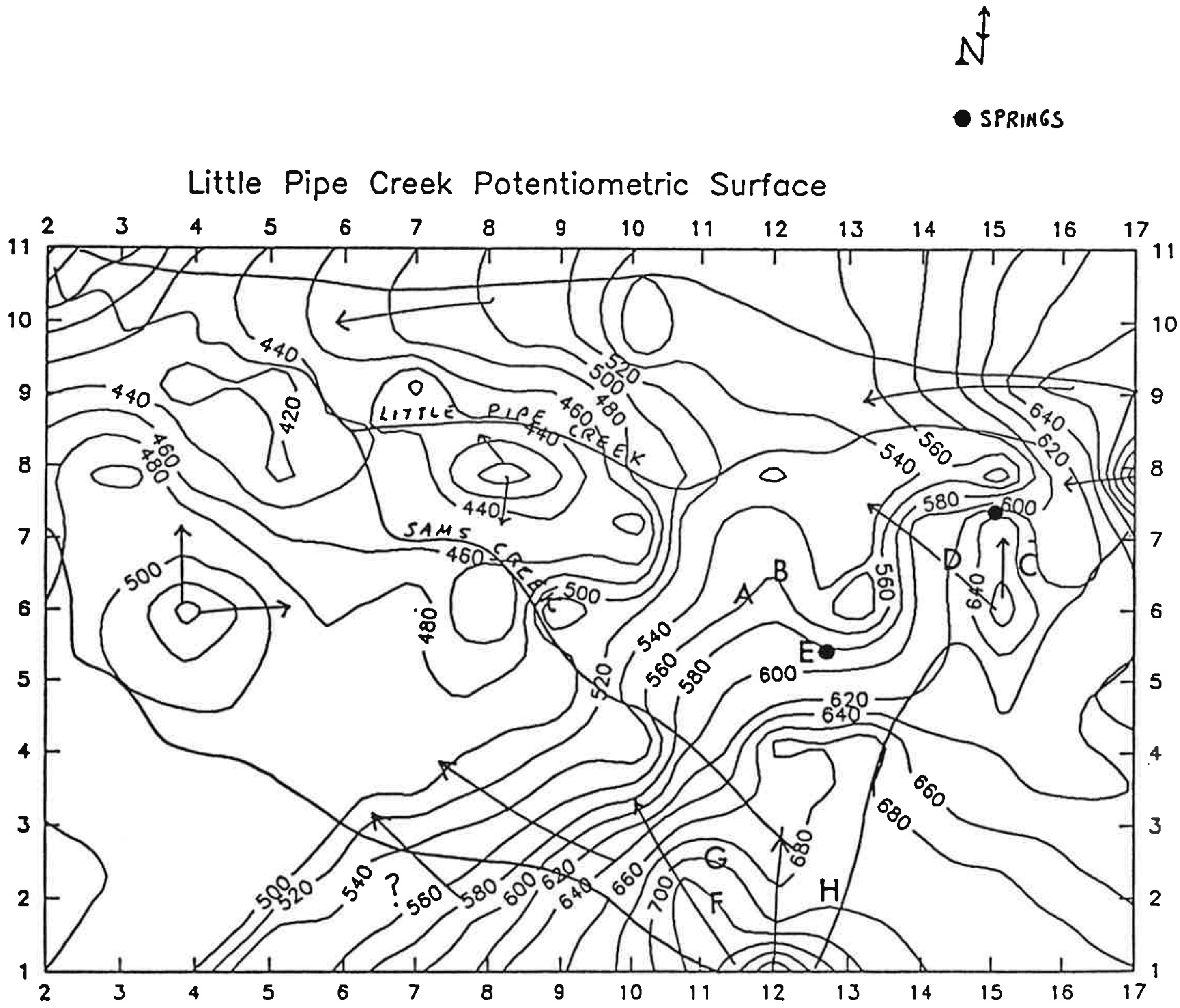
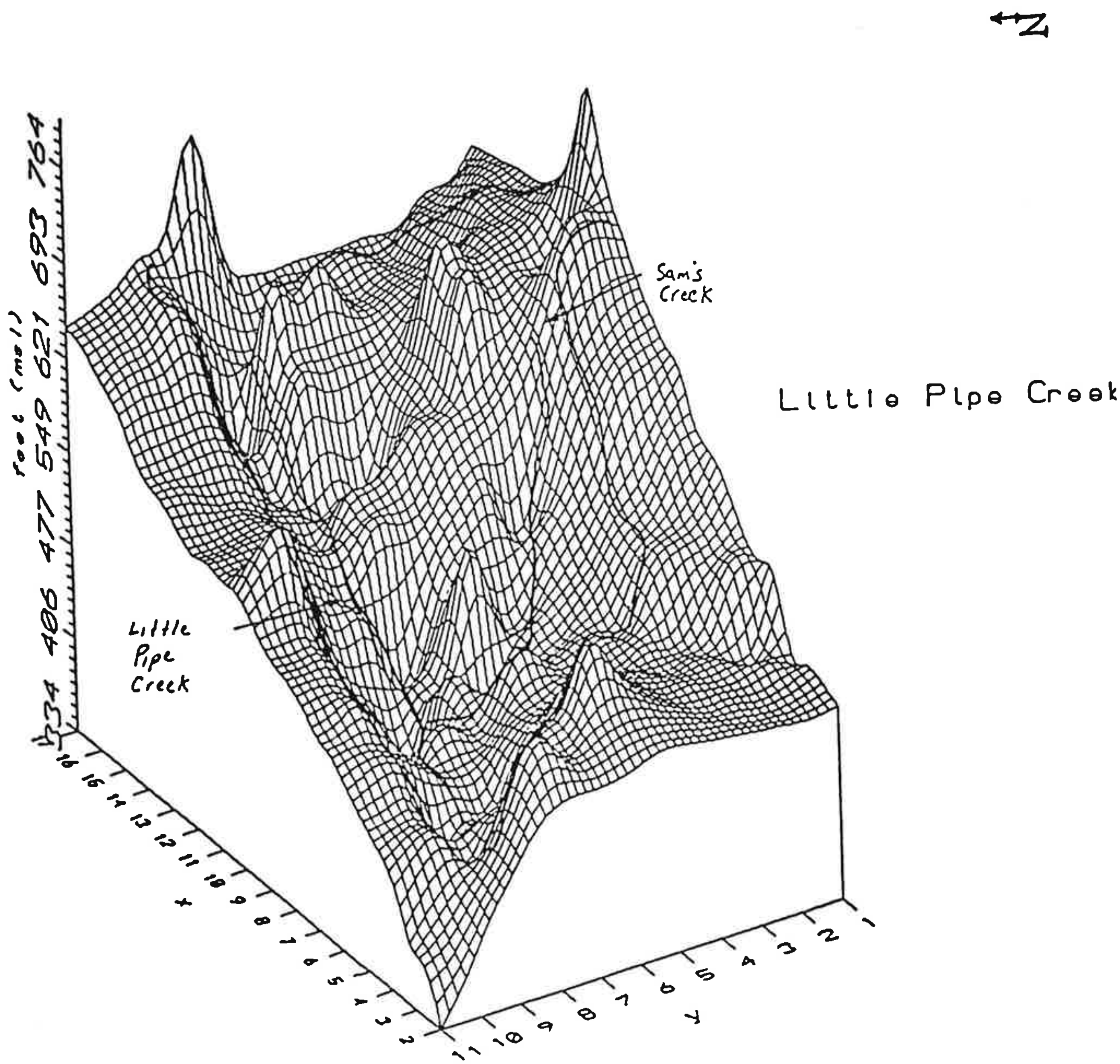


Figure 4. 3-D Potentiometric Surface Map of Little Pipe Creek Basin



ISRAEL CREEK BASIN

HYDROLOGY

Unlike the previously discussed flow patterns the ground water flow lines for the Israel Creek basin indicate that most flow is directed toward the Monocacy River (Figure 5 and 6). Much of the western part of this basin (near the Monocacy) is underlain by limestone deposits. The preponderance of springs in this area is a good indicator of this. The spring located on Figures 3 and 4 has an extremely large discharge that is utilized for a commercial operation, and there are several other springs with discharges that exceed 25 gallons per minute. This area has some of the highest hydraulic conductivities in the entire Monocacy Basin, and where solution openings are large enough, there could be a high potential for pollution transport from the ground water to the Monocacy. Spring discharge rates are listed in Table 3.

Table 3. ISRAEL CREEK SPRING DISCHARGES

Grid Location (miles)	Discharge (gallons/minute)
(4,7)	25
(3,6)	30
(2,6)	10
(3,7)	10
(4,6)	11
(7,4)	-
(6,7)	-
(6,5)	15
(7,7)	-
(5,7)	145
(9,8)	10
(5,3)	-
(3,4)	1020
(5,2)	10
(4,5)	40
(4,2)	15
(2,4)	50

"-" indicates missing data

There were seven wells in this sub-basin where depth to water was measured seasonally. The low and high water levels are listed in Table 4 for each of these wells giving an indication of the change in the thickness of the saturated zone (and therefore, unsaturated zone) throughout a yearly cycle. The average change from these wells was 9 feet. The largest change was 19 feet and was located at grid location (7,10). It is not possible to find any correlation with these water level changes and other hydrogeologic factors with these data (i.e. we cannot conclude that, for example, the limestone areas exhibit larger or smaller magnitude changes in seasonal ground water levels than areas with different geology).

Table 4. WATER LEVEL CHANGES IN ISRAEL CREEK WELLS

Grid Location (miles)	Formation	Low Level (elevated feet)	High Level (elevated feet)
(5,8)	Grove Limestone	400	410
(6,8)	Fred. Limestone	324	328
(6,11)	New Oxford	381	385
(7,10)	New Oxford	461	480
(10,8)	Ijamsville	558	572
(3,5)	Grove Limestone	271	283
(6,5)	Fred. Limestone	304	313

The depth to ground water measurements are displayed on Figure 7. The asterisks show the actual data that were used to create this contour map. It can be seen from this map that the water table is much closer to the land surface in the western part of the basin. This area is underlain by limestone deposits and is topographically low lying land. (The border of this sub-basin is the Monocacy River itself, and the low elevations reflect this.) As mentioned previously, the limestone areas may have high hydraulic conductivities. This combines with shallow water tables to produce potentially sensitive ground water areas. Also the overall slope of the ground water seems to be toward the western side (where the most springs are found) and suggests that the aquifers are connected to the Monocacy River channel.

WATER QUALITY

The ground water quality data show that nitrate levels are fairly high in some shallow wells, but there is a lack of phosphorus data in this basin. Pionke, et al., (1986) looked at contamination of ground water in a Pennsylvania watershed. Though no predictive equations could be developed, they suggest that nitrate-nitrogen concentrations above 4.0 ppm may serve to flag ground water where higher pesticide concentrations might be expected.

Table 5. **NITROGEN and PHOSPHORUS CONCENTRATES IN ISRAEL CREEK WELLS**

Location	Nitrogen (mg/l)	Total Phosphorus (mg/l-P)	Depth (feet below land)
A	7.7 (NO_3)	-	15
B	7.8 "	-	15
C	6.6 "	-	40
D	0.16 "	-	20
E	5.4 "	-	20
F	9.0 "	-	30
G	5.9 "	-	50
H	6.6 "	-	15
I	8.8 (NO_2+NO_3)	0.05	13

"-" indicates missing data

Nitrogen contamination of ground water in Israel Creek wells is significantly higher than that of the Double Pipe Creek watershed. The ground water is fairly shallow in parts of the sub-basin, particularly in the Glade Creek area. This means that the potential for recharge to the ground water with nutrient laden waters is high if the land use supplies large amounts of nutrients to the surface. As mentioned previously, this area can be expected to have hydraulic conductivities that are among the highest in the Monocacy Basin. This suggests that ground water may be a significant source of nutrient loading to the Monocacy in this area.

Figure 5. Potentiometric Surface of Israel Creek Basin

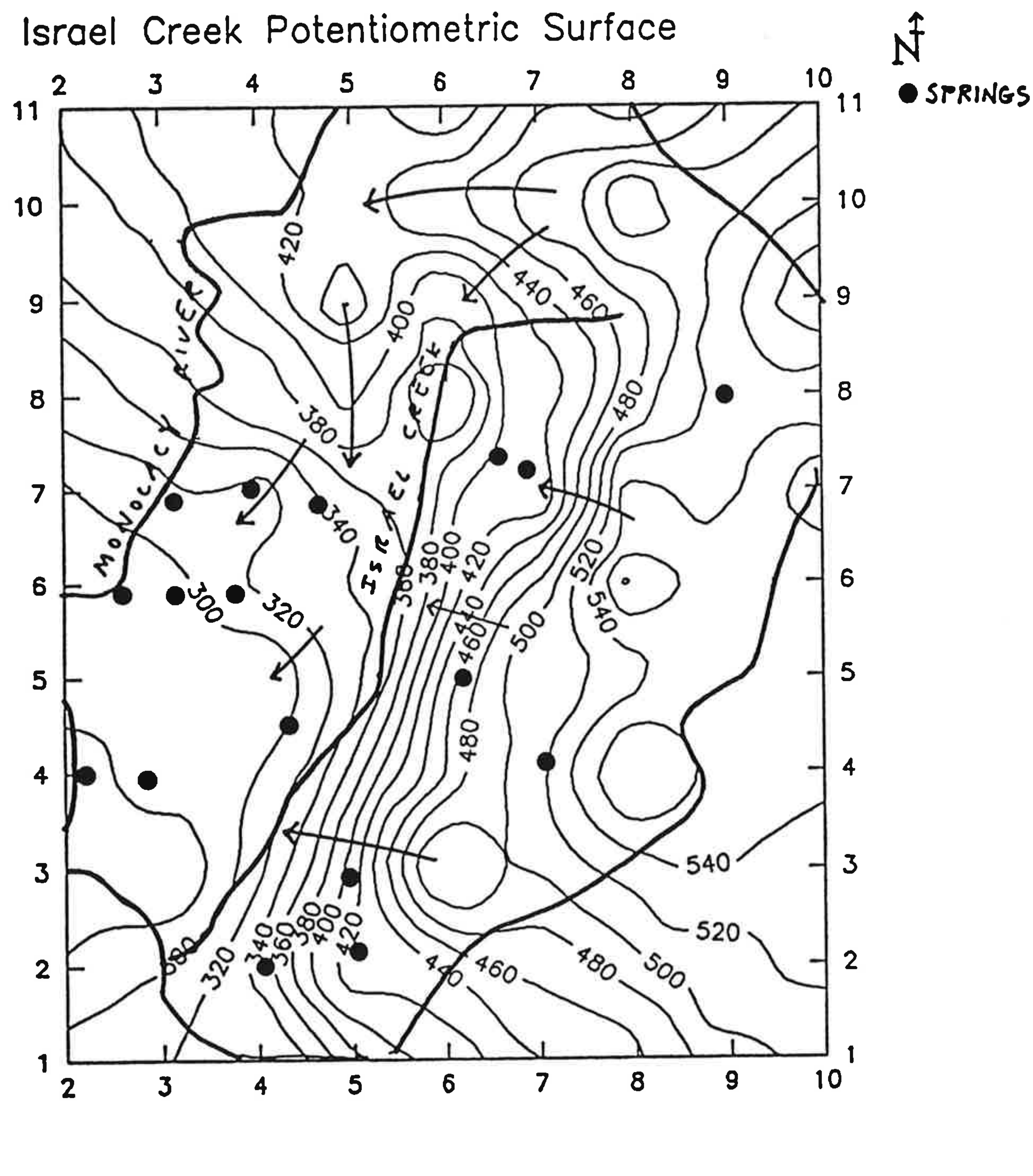


Figure 6. 3-D Potentiometric Surface Map of Israel Creek Basin

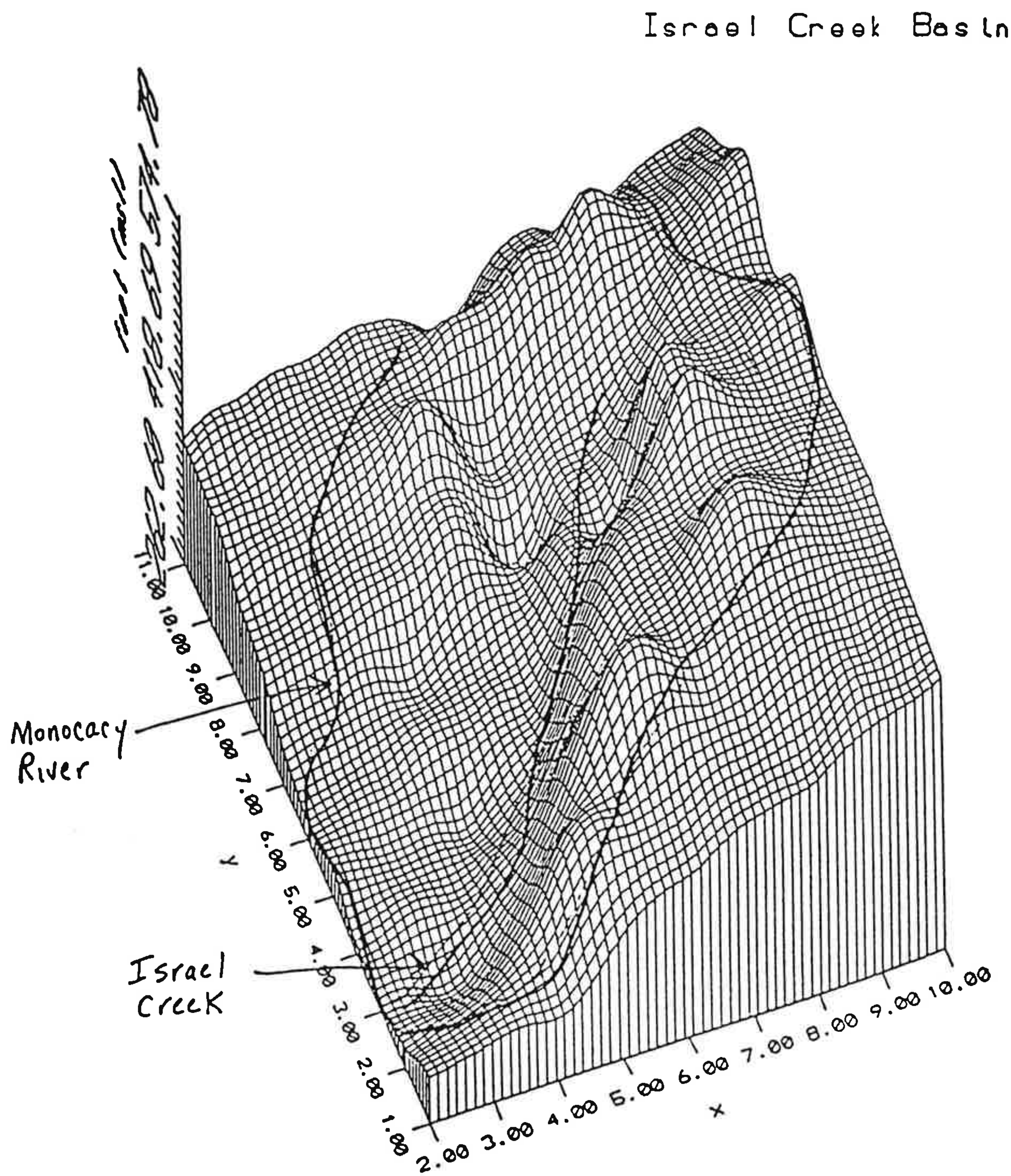
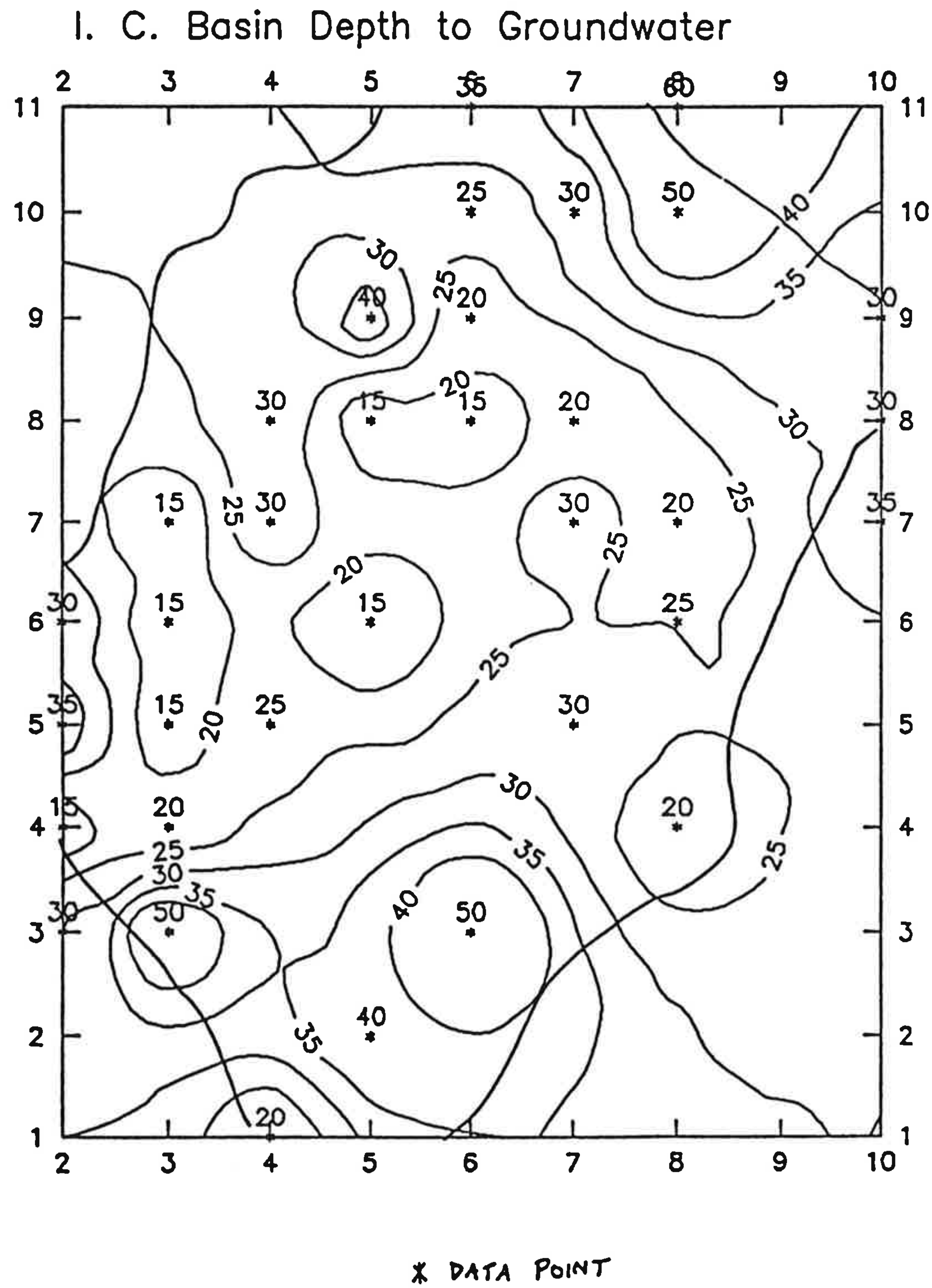


Figure 7. Depth to Water Table Map for Israel Creek Basin



LINGANORE CREEK BASIN

HYDROLOGY

The ground water flow lines indicate that most subsurface flow in the Linganore Creek sub-basin is directed towards the west (Figure 8 and 9). The western outfall of this basin is at the Monocacy River. Flowlines seem to converge towards the western part of the basin (near Linganore Lake area) indicating that ground water discharge areas may be significant in this area. This conclusion is supported by the fact that this part of the basin has the most shallow water tables. (See Figure 11, a map of the depth to ground water.) The springs seem to be scattered throughout the basin with no apparent spatial pattern. However, there were some data available on the discharge rates of these springs which are presented in Table 6. It is difficult to draw any quantitative conclusions from these data but it appears that the eastern half of the basin has springs with higher discharges than the western half.

Table 6. LINGANORE SPRING DISCHARGES

Grid Location (miles)	Discharge (gallons/minute)	
(15,7)	8	East
(14,8)	3	East
(4,5)	15	West
(6,5)	5	West
(9,8)	50	East
(12,7)	18	East
(6,4)	30	West
(11,3)	100	East

Water level changes were monitored in only three wells in this basin. Two of these wells were located within the same grid cell location (3,4). It is not possible to find any correlation with these water level changes and other hydrogeologic factors with this data. However, the change in the thickness of the unsaturated zone can be inferred.

Table 7. WATER LEVEL CHANGES IN LINGANORE CREEK WELLS

Grid Location (miles)	Low Level (elevated Feet)	High Level
(3,4)	510	526
(3,4)	246	249
(11,2)	636	642

WATER QUALITY

The ground water quality data show that nitrate concentrations are fairly high towards the center of the basin. A map of nitrate nitrogen levels in the basin are shown in Figure 10. The entire basin is not represented due to the paucity of data. Nitrite + nitrate nitrogen data were recorded in the Carroll County portion of this basin, and though they are not listed on the map, they are included in Table 8 for completeness. Phosphorus data were scarce in this basin.

Table 8. NITROGEN and PHOSPHORUS CONCENTRATIONS LINGANORE CREEK WELLS

Location	Nitrogen (mg/l)		Total Phosphorus (mg/l-P)	Depth (feet below land)
A	11.0	(NO_3)	-	10
B	-	"	0.05	-
C	2.5	"	-	-
D	3.6	"	-	10
E	7.9	"	0.01	-
F	1.3	"	-	-
G	14.0	"	-	-
H	7.7	"	-	-
I	9.9	"	-	-
J	0.05	"	-	40
K	4.5	"	-	-
L	2.9	"	-	30
M	9.7	"	-	30
N	0.14	"	-	40
O	1.5	(NO_2+NO_3)	-	48
P	5.0	"	0.005	32
Q	0.93	"	0.01	40
R	1.4	"	-	48
S	0.7	"	-	-
T	3.4	"	-	36

"-" indicates missing data

Figure 8. Potentiometric Surface of Linganore Creek Basin

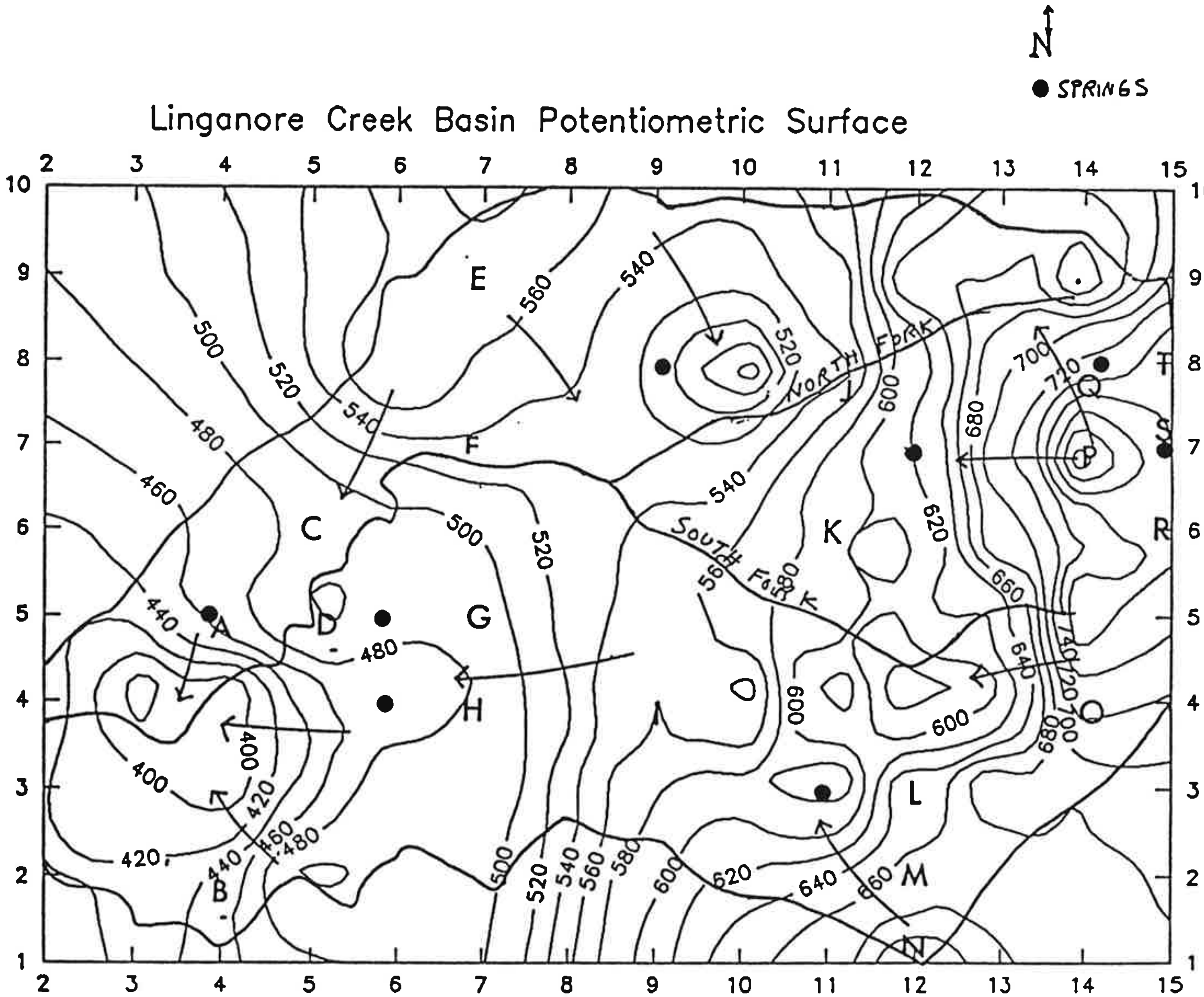


Figure 9. 3-D Potentiometric Surface Map of Linganore Creek Basin

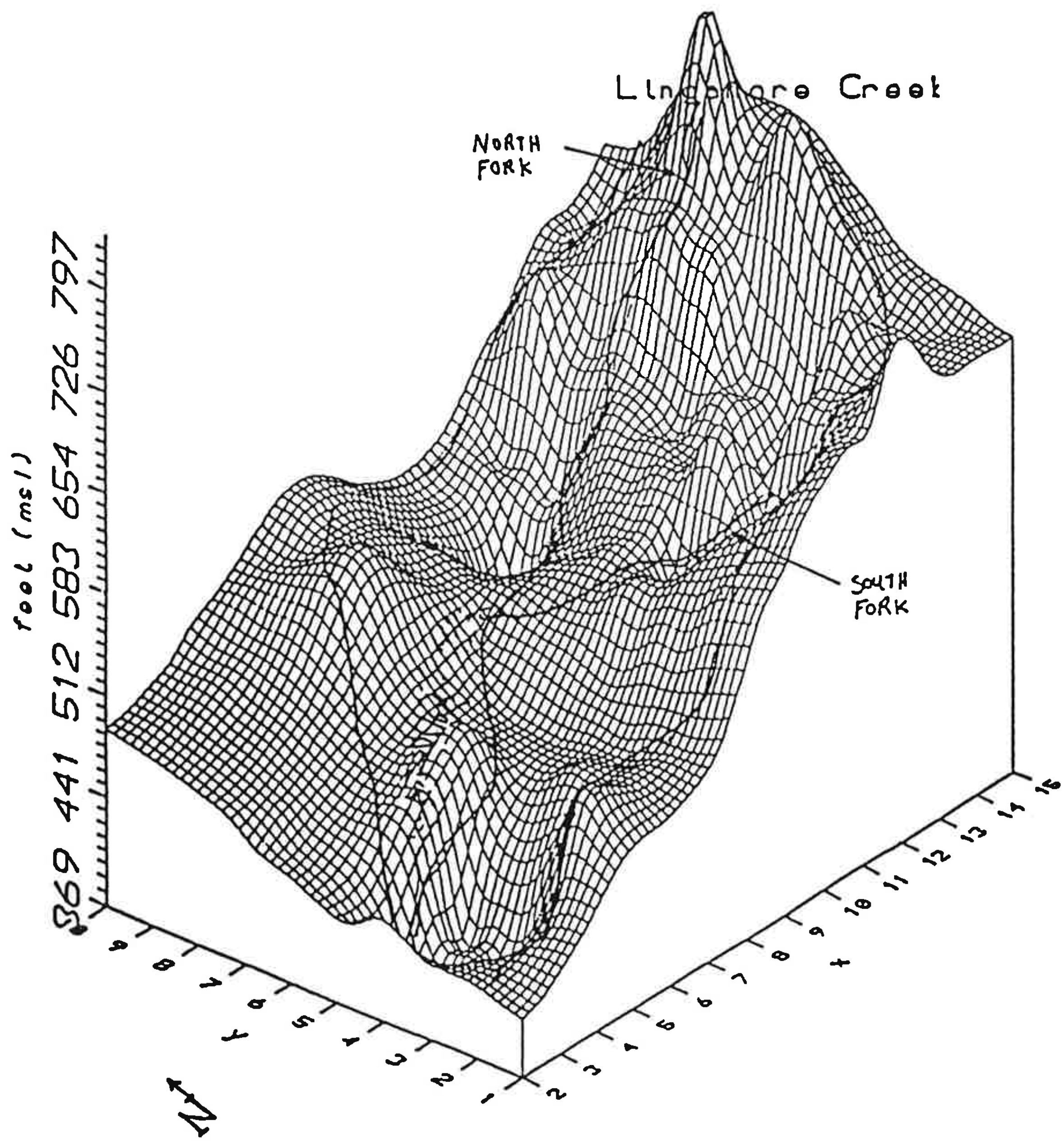


Figure 10. Nitrogen Data for Linganore Creek Basin

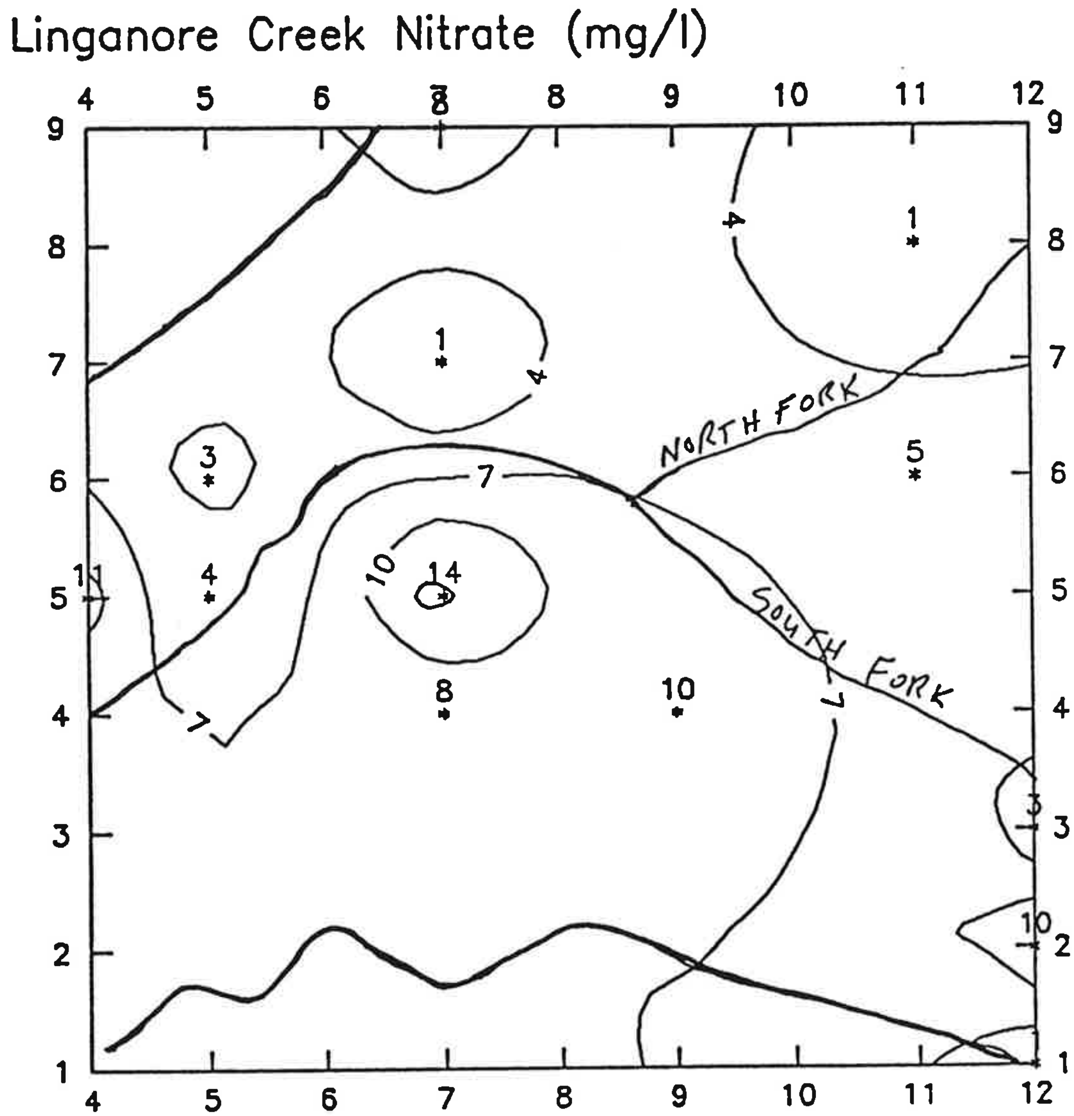
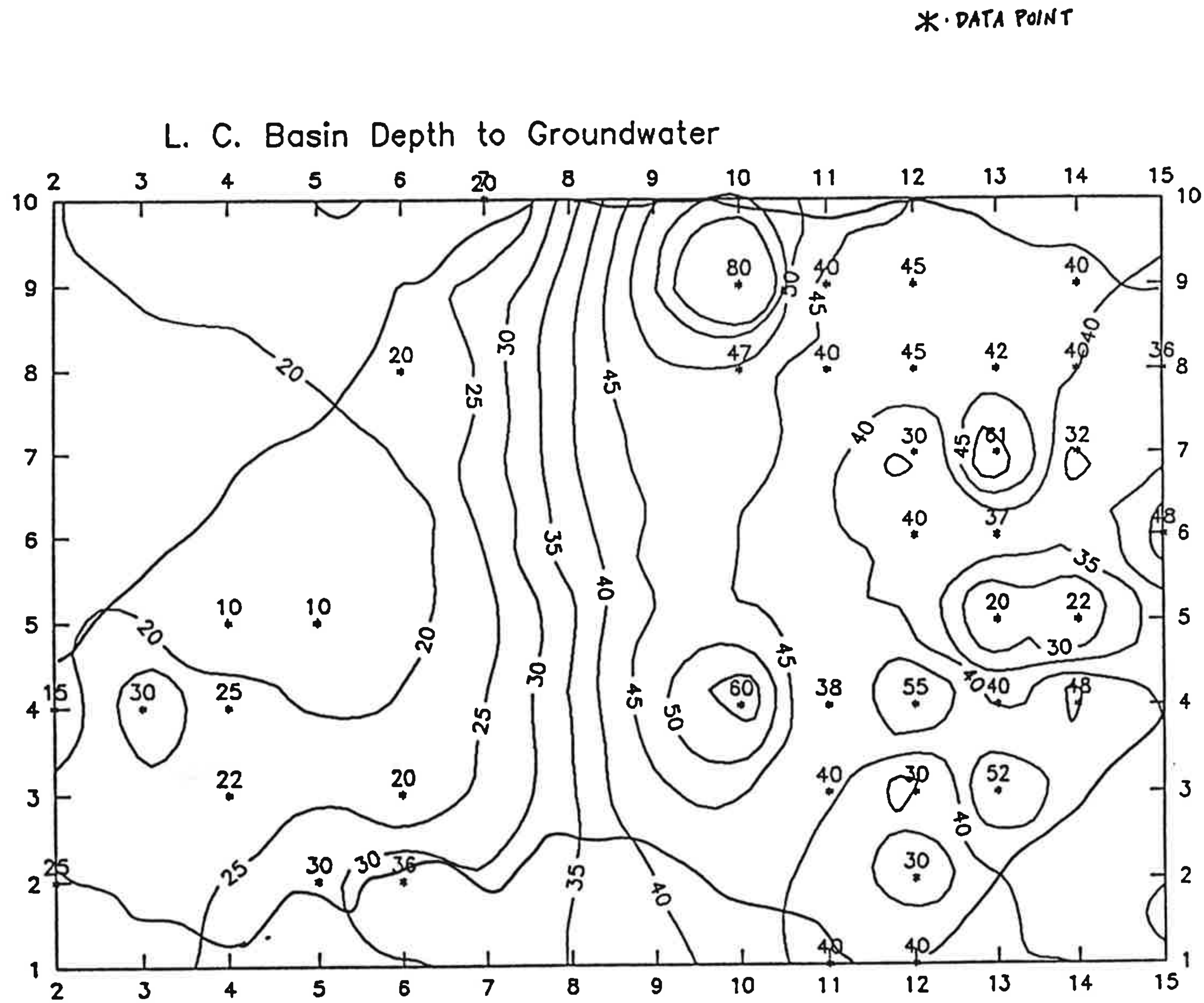


Figure 11. Depth to Water Table Map for Linganore Creek Basin



BUSH CREEK BASIN

HYDROLOGY

The ground water flow lines indicate that most flow is directed towards the west of the basin towards Hunting Creek's outfall (Figures 12 and 13). The data used to create this potentiometric map are indicated by "*". There were only ten wells possessing the required data record in this basin. Figures 32 and 33 shows how the software used to create these maps functions with scarce data. The overall direction of ground water flow is captured by this method, however the contour lines tend to bend and turn in strange directions at particular locations (e.g. cell (10,1)-(10,2)). Therefore, the hydraulic gradients should be calculated with this in mind and some judgment will be necessary.

There was only one spring listed for this basin. Water level changes were monitored in five wells (Table 9). The ranges in water levels found are fairly consistent with those of other neighboring basins. In general, the depth to water is greater in higher elevations.

Table 9. WATER LEVEL CHANGES IN BUSH CREEK WELLS

Grid Location (miles)	Low Level (elevated Feet)	High Level (elevated Feet)	Change (feet)	Land Surface (elev.feet)
(12,5)	529	531	2	550
(12,3)	525	533	8	565
(12,2)	554	582	28	610
(17,3)	798	813	15	840
(7,1)	390	394	4	420

WATER QUALITY

Nutrient levels seem to be fairly high in this basin in the six wells monitored (Table 10).

Table 10. NITROGEN and PHOSPHORUS CONCENTRATIONS BUSH CREEK WELLS

Location	Nitrogen (mg/l)	Ortho Phosphorus (mg/l-P)	Depth (feet below land)
A	3.8 (NO_3)	-	-
B	0.94(NO_2+NO_3)	0.05	-
C	4.8 "	0.01	-
D	7.1 "	0.02	45
E	2.5 (NO_3)	-	-
F	9.5 "	-	42

"-" indicates missing data

Figure 12. Potentiometric Surface of Bush Creek Basin

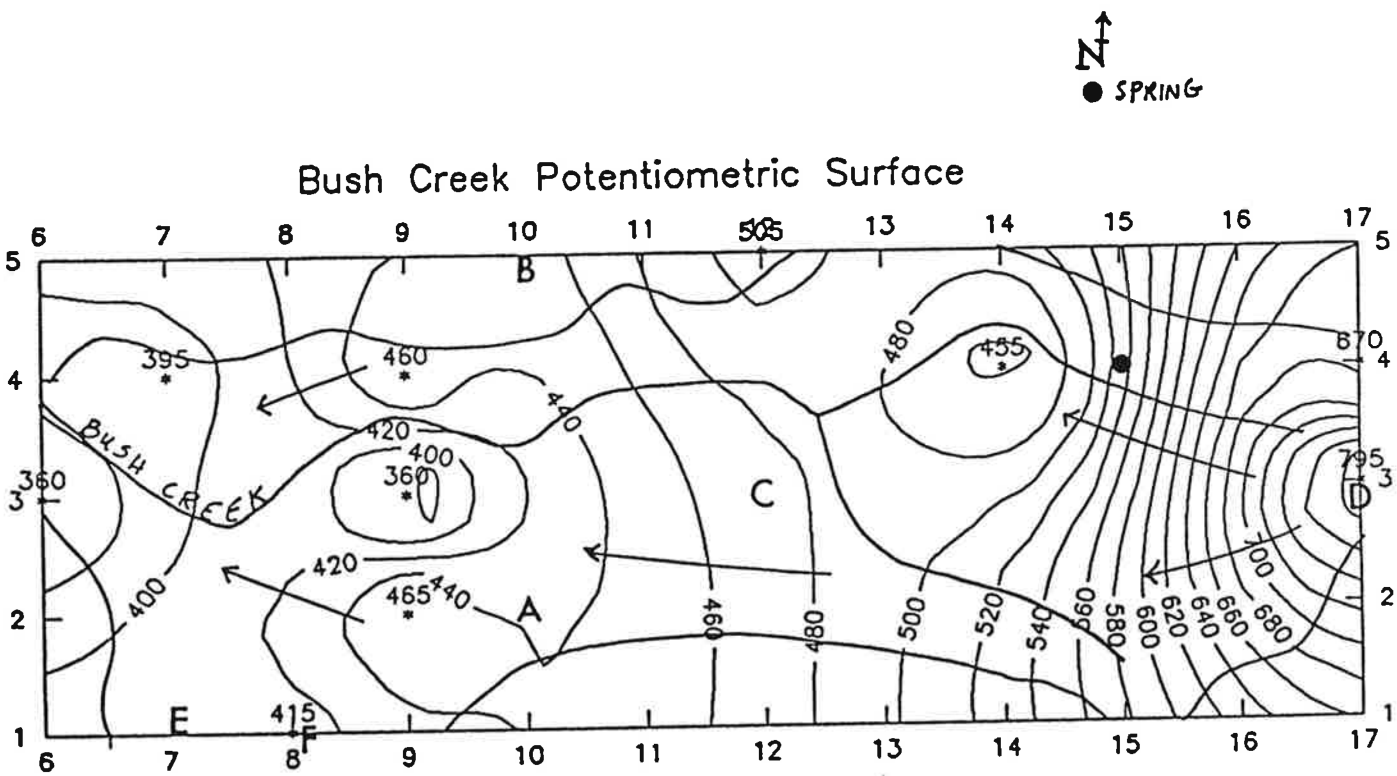
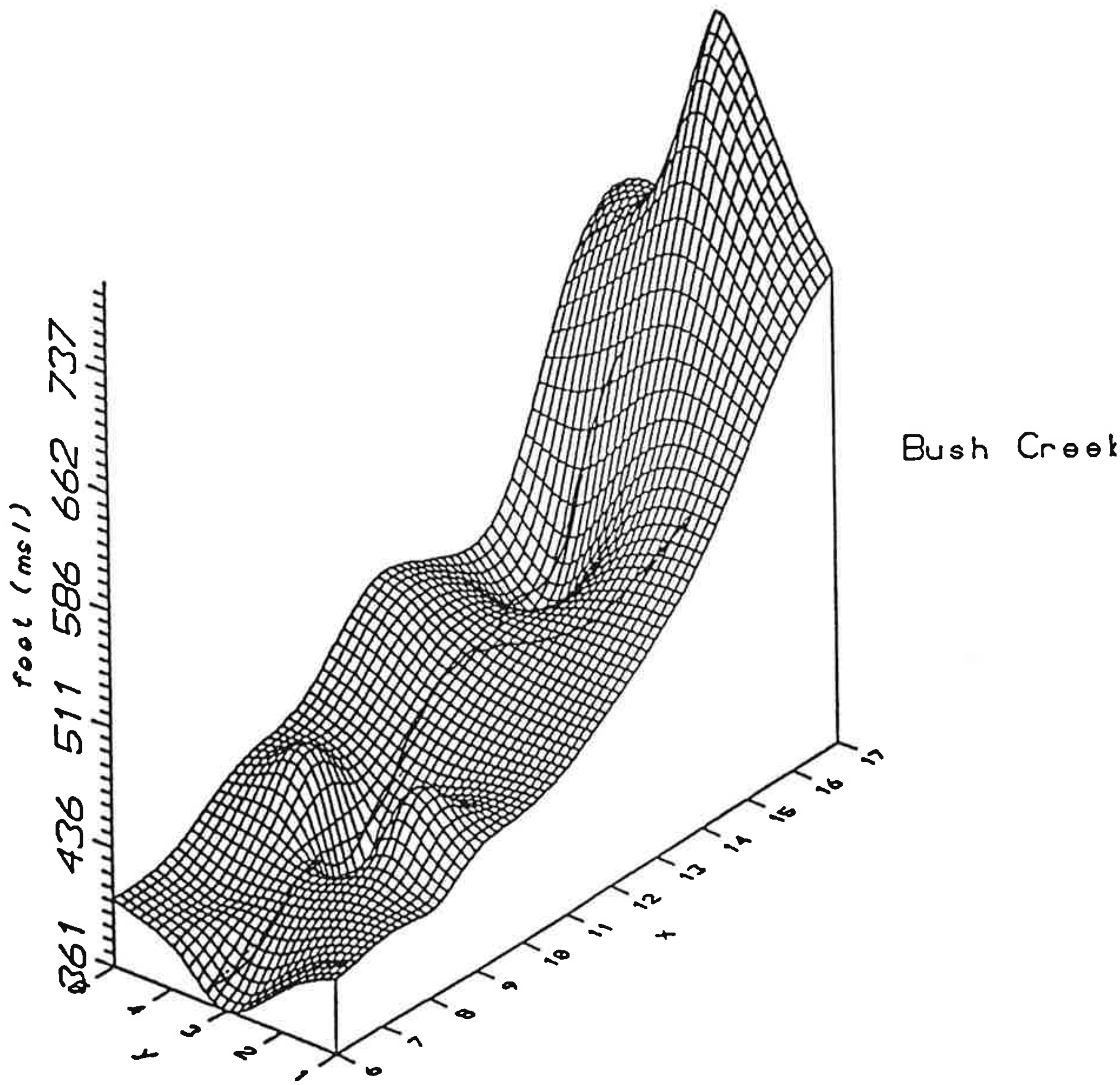


Figure 13. 3-D Potentiometric Surface Map of Bush Creek Basin



BENNETT CREEK BASIN

HYDROLOGY

Most ground water flow is directed towards the west part of the Bennett Creek basin towards the Monocacy River (Figures 14 and 15). There were only two springs listed for this basin, and they had only moderate discharges. Water levels were measured in two wells with neither exhibiting any drastic fluctuations. The first well was located at (1,5) and changed from a low of 16 feet below ground to 10.6 feet below ground. The second well was at (3,5) and ranged from 23 feet below ground to 15.7 feet below ground. These fluctuations are typical seasonal values for relatively shallow wells in the lowlands.

There is a local depression in the potentiometric surface around cell (1,5) (this can be seen clearly in the 3-D plot, Figure 15). This is in the area of the Lilypons Fish Hatchery. The shape of the surface in this localized area is mostly an artifact of scarce data and the mathematical technique used to interpolate between data points. However, it is reasonable to infer that this is a ground water discharge area.

Due to the paucity of data in the area around Sugarloaf Mountain (i.e. around cells #3,2 - 3,3) the ground water surface is rather smooth and the effects of the mountain on the regional flow field are masked.

WATER QUALITY

There were no phosphorus concentration data listed for wells in this basin, but several wells provided nitrate records. It is difficult to draw conclusions from this data, but some relatively shallow wells seem to have fairly high levels of nitrate. These data span many decades, (Table 11).

**Table 11. NITROGEN and PHOSPHORUS CONCENTRATIONS
BENNETT CREEK WELLS**

Location	Nitrogen (mg/l)		Total Phosphorus (mg/l-P)	Depth-water table* (feet)
A	1.4	(NO_3)	-	2
B	3.4	"	-	shallow
C	7.9	"	-	16
D	0.1	"	-	48
E	13.0	"	-	-
F	5.0	"	-	shallow
G	3.8	"	-	-
H	1.2	"	-	32

"-" indicates missing data

* "shallow" indicates that an actual measurement was not available for the well but the ground water was inferred to be shallow based on the topographic location of the well. "-" indicates missing data and a well that is not in a topographic low spot.

Figure 14. Potentiometric Surface of Bennett Creek Basin

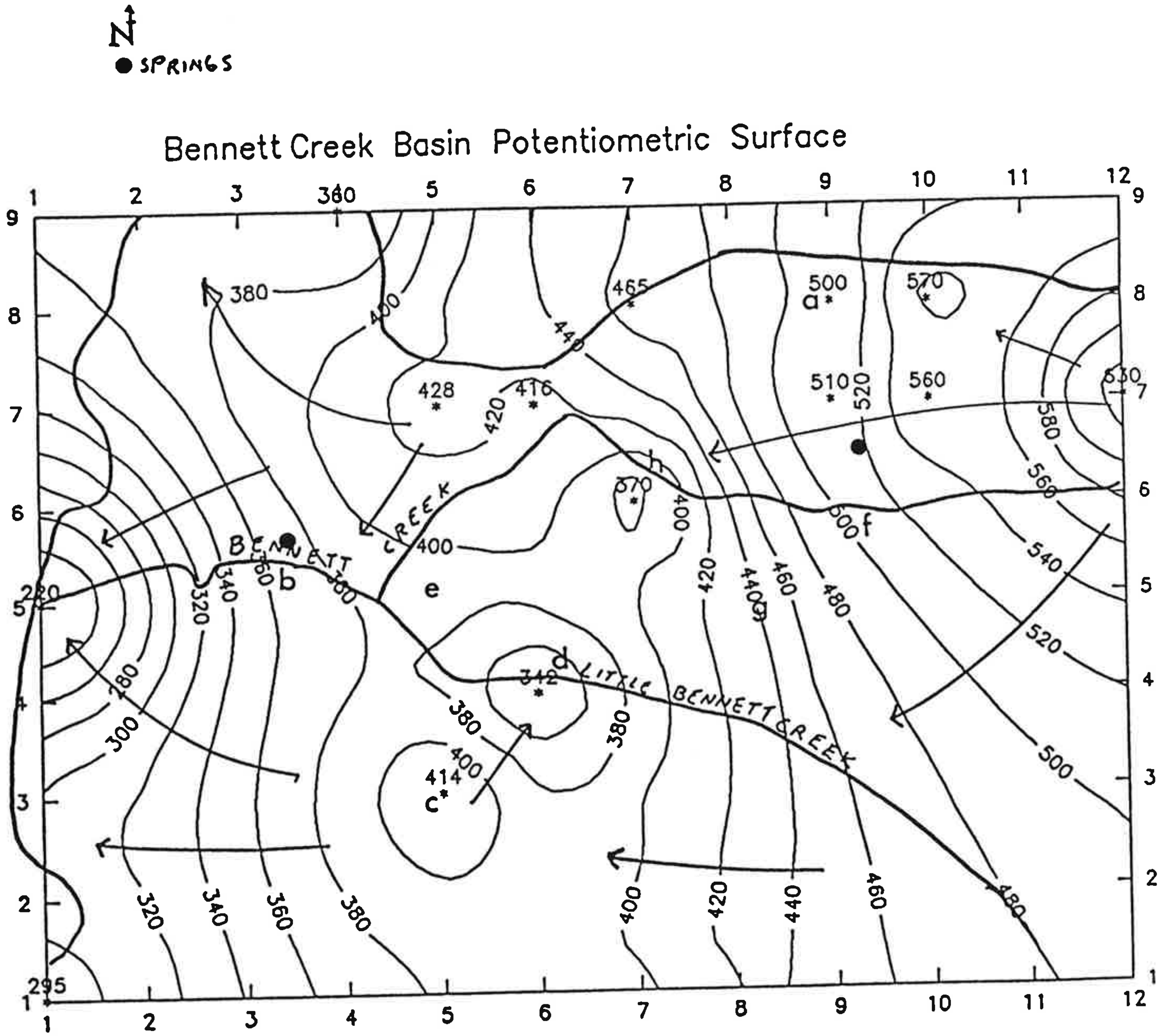
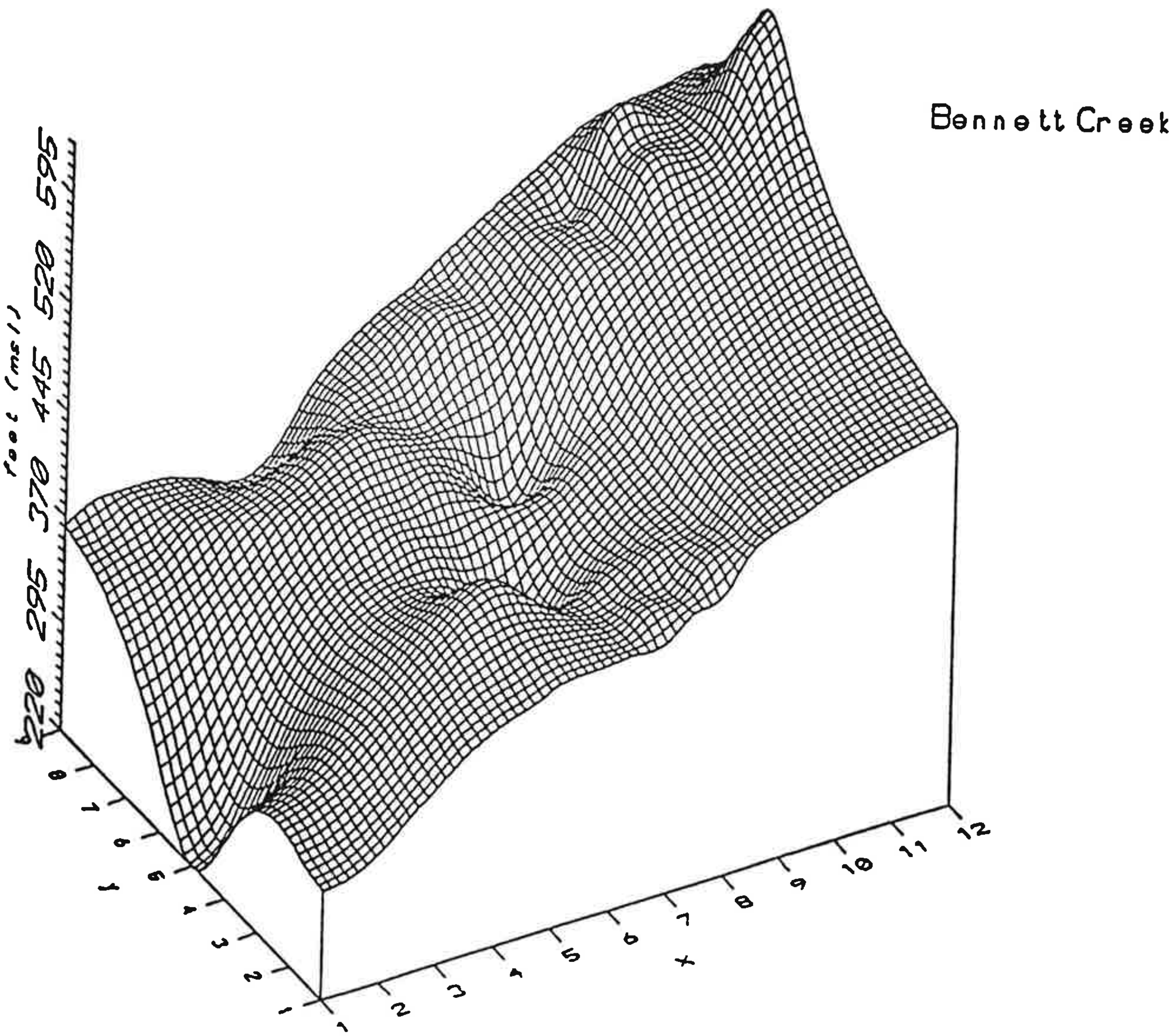


Figure 15. 3-D Potentiometric Surface Map of Bennett Creek Basin



CARROLL/BALLENGER CREEK BASIN

HYDROLOGY

Carroll Creek and Ballenger Creek are discussed together. Most of the available data were concentrated near the drainage divide of the two sub-basins, and the long southern part of Ballenger Creek had very little data.

Most ground water flow is directed towards the west part of the basin to the Monocacy River (Figure 16 and 17). Locally, the ground water flows to the smaller tributaries but the overall movement is towards the Monocacy. The most unique feature of this area is the large number of springs. It is clear from the contour map that they are oriented along the limestone valley, and therefore, the hydrogeology is different than most of the other parts of the Monocacy basin. One would anticipate high hydraulic conductivities for this area. The discharges in the springs ranged from no flow to 402 gallons per minute. The highest discharges were found in the lower lying areas.

Water level changes were monitored in five wells in this basin. The ranges in water levels found in this basin are similar to those found in other basins. The change ranged from 7 to 29 feet.

WATER QUALITY

The ground water quality data show that nitrite + nitrate nitrogen concentrations were at some time fairly high in some of the wells drilled in the Frederick Limestone formation. Well "F" was monitored in 1956 and had 40 mg/l of nitrate-nitrogen and a pH of 8.0. Well "J" was also drilled in the limestone and had 21 mg/l of nitrite + nitrate nitrogen in 1982. Phosphorus data were lacking in this basin but Wells "E" and "I" had high concentrations. Both of these wells were also drilled in the Frederick Limestone, and both were sampled in 1982.

Table 12. NITROGEN and PHOSPHORUS CONCENTRATIONS CARROLL/BALLENGER CREEK WELLS

Location	Nitrogen (mg/l)		Phosphorus* (mg/l-P)	
A	7.2	(NO_3)	-	
B	1.3	"	-	
C	3.6	"	-	
D	8.1	"	-	
E	6.1	"	0.09	
F	40.0	"	-	
G	4.3	"	-	
H	8.1	"	-	
I	5.8	(NO_2+NO_3)	0.21	
J	21.0	"	<0.01	(Ortho)

"-" indicates missing data

*Total phosphorus unless otherwise indicated.

Figure 16. Potentiometric Surface of Carroll Ballenger Basin

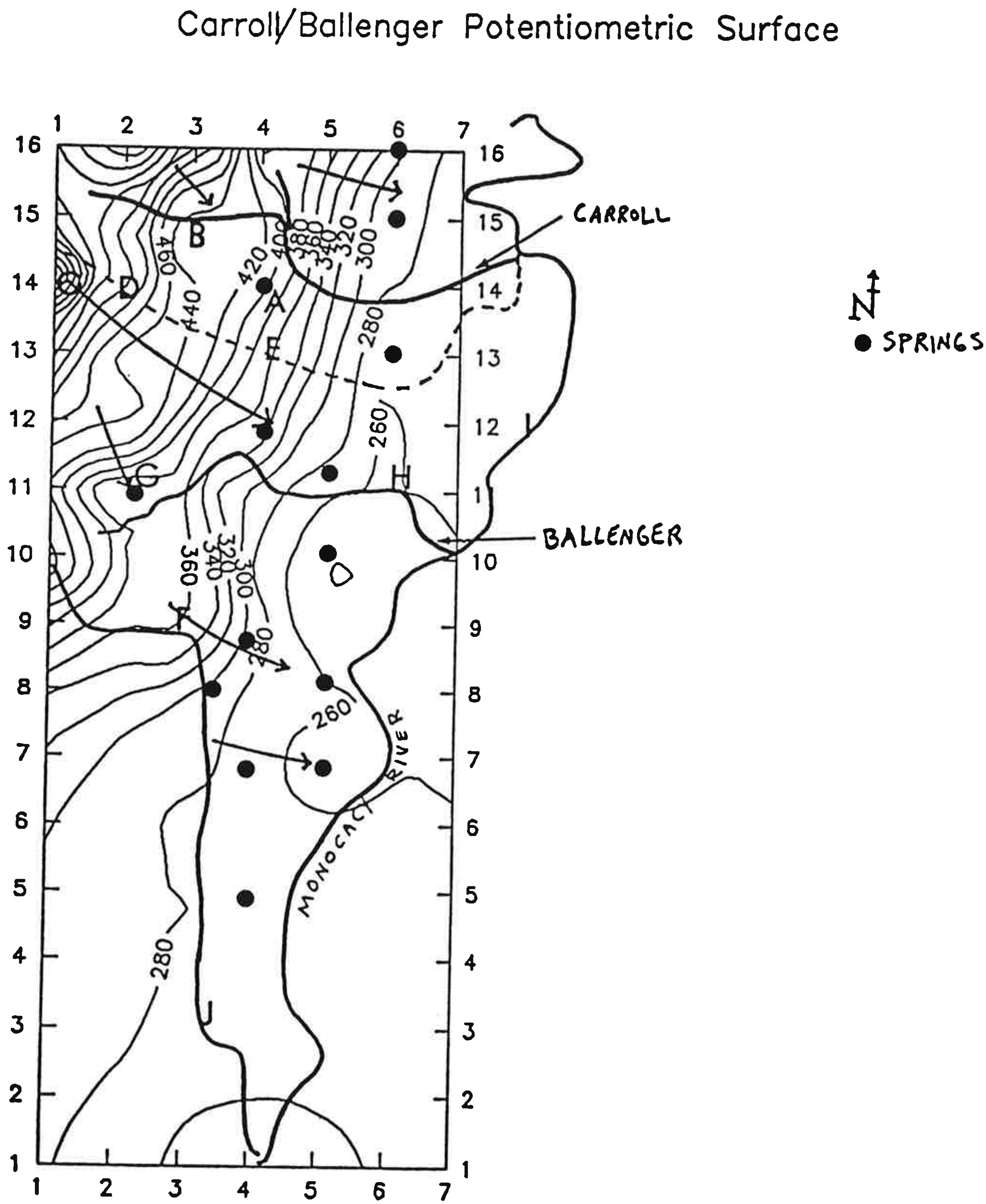
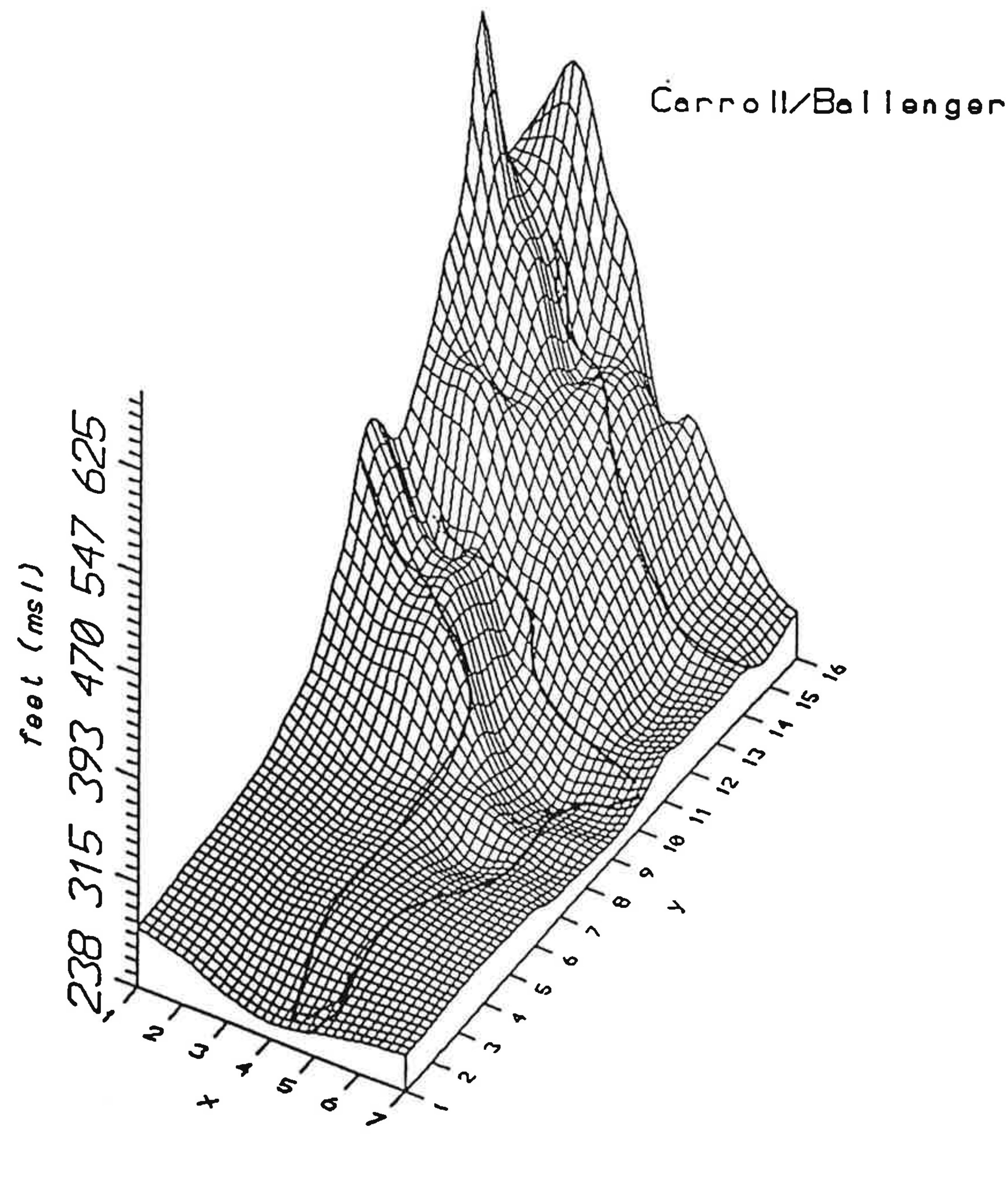


Figure 17. 3-D Potentiometric Surface Map of Carroll/Ballenger Basin



TUSCARORA CREEK BASIN

HYDROLOGY

Most subsurface flow is directed toward Tuscarora Creek and the Monocacy valley (Figures 18 and 19). The western part of the basin is in the Catoctin Mountains and has no data. The eastern part of the basin is underlain by limestone, and the largest spring discharges in the sub-basin are found in this area. The difference between spring discharges located in the mountains (i.e. (1,2), (1,3), and (2,4)) and those in the limestone valley (e.g. (6,1), (7,3)) are large (Table 13).

Table 13. TUSCARORA SPRING DISCHARGES

Grid Location (miles)	Discharge (gallons/minute)
(1,2)	-
(1,3)	5
(2,4)	1
(4,4)	100
(5,3)	8
(6,1)	67
(6,2)	10
(6,3)	86
(7,3)	125

There were two wells in this area where depth to water was measured seasonally. There was a 15 foot change in the well located at (4,5) and a 2 foot change in the well located at (4,2).

WATER QUALITY

The ground water quality data were only available for five wells in this basin. The nitrate levels seem a little high. Phosphorus data were lacking (Table 14).

Table 14. NITROGEN and PHOSPHORUS CONCENTRATIONS TUSCARORA CREEK WELLS

Location	Nitrogen (mg/l)	Total Phosphorus (mg/l-P)	Depth (feet below land)
A	2.2 (NO_2+NO_3)	0.05	31
B	3.6 (NO_3)	-	35
C	5.1 "	-	31
D	4.1 "	-	15
E	4.1 "	-	30

"-" indicates missing data

The ground water is fairly shallow in parts of the basin. This means that the potential for recharge to the ground water with nutrient laden waters is high. As mentioned previously, this area can be expected to have hydraulic conductivities that are among the highest in the Monocacy basin. This suggests that ground water may be a significant source of nutrient loading to the Monocacy in this area.

Figure 18. Potentiometric Surface of Tuscarora Creek Basin

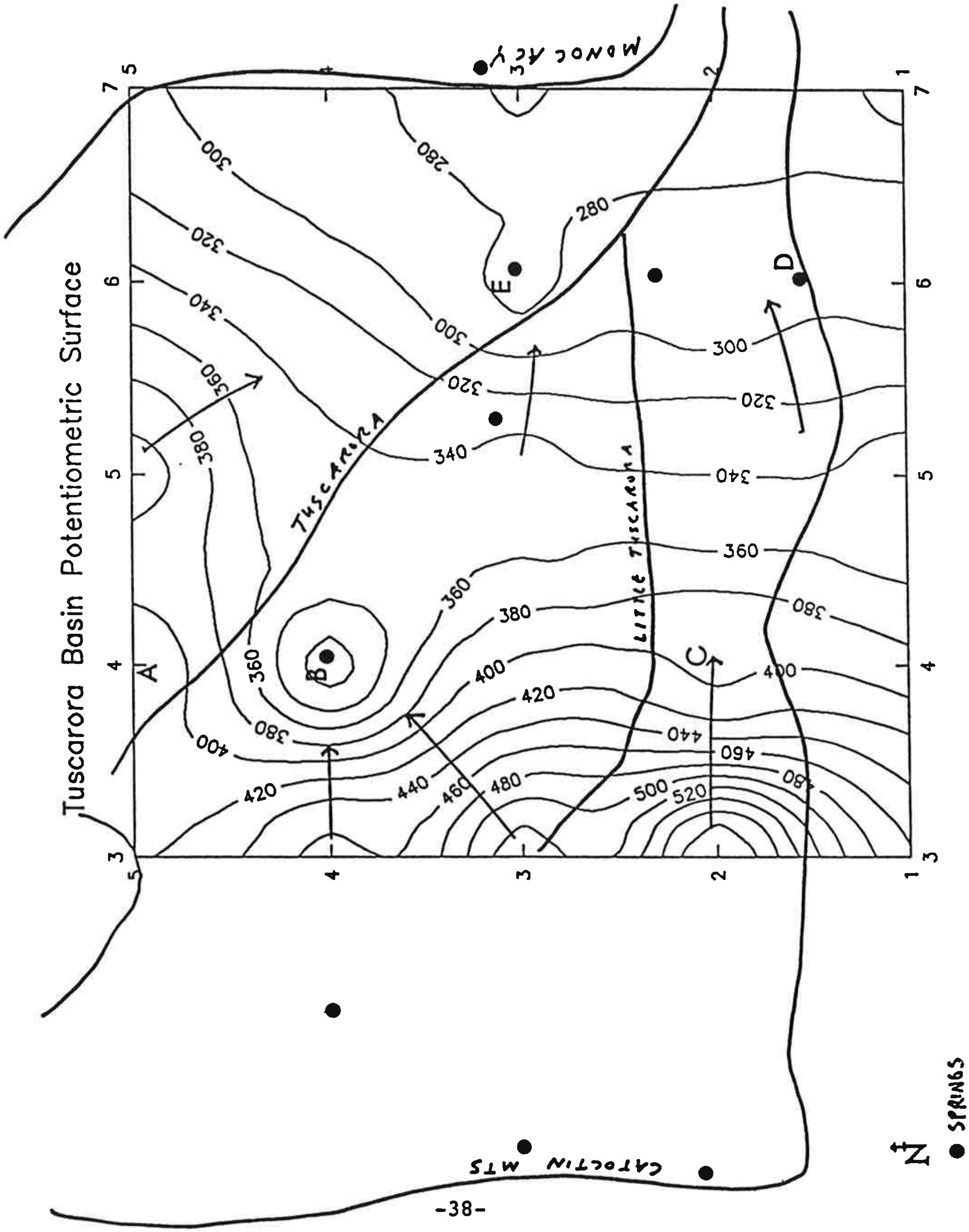
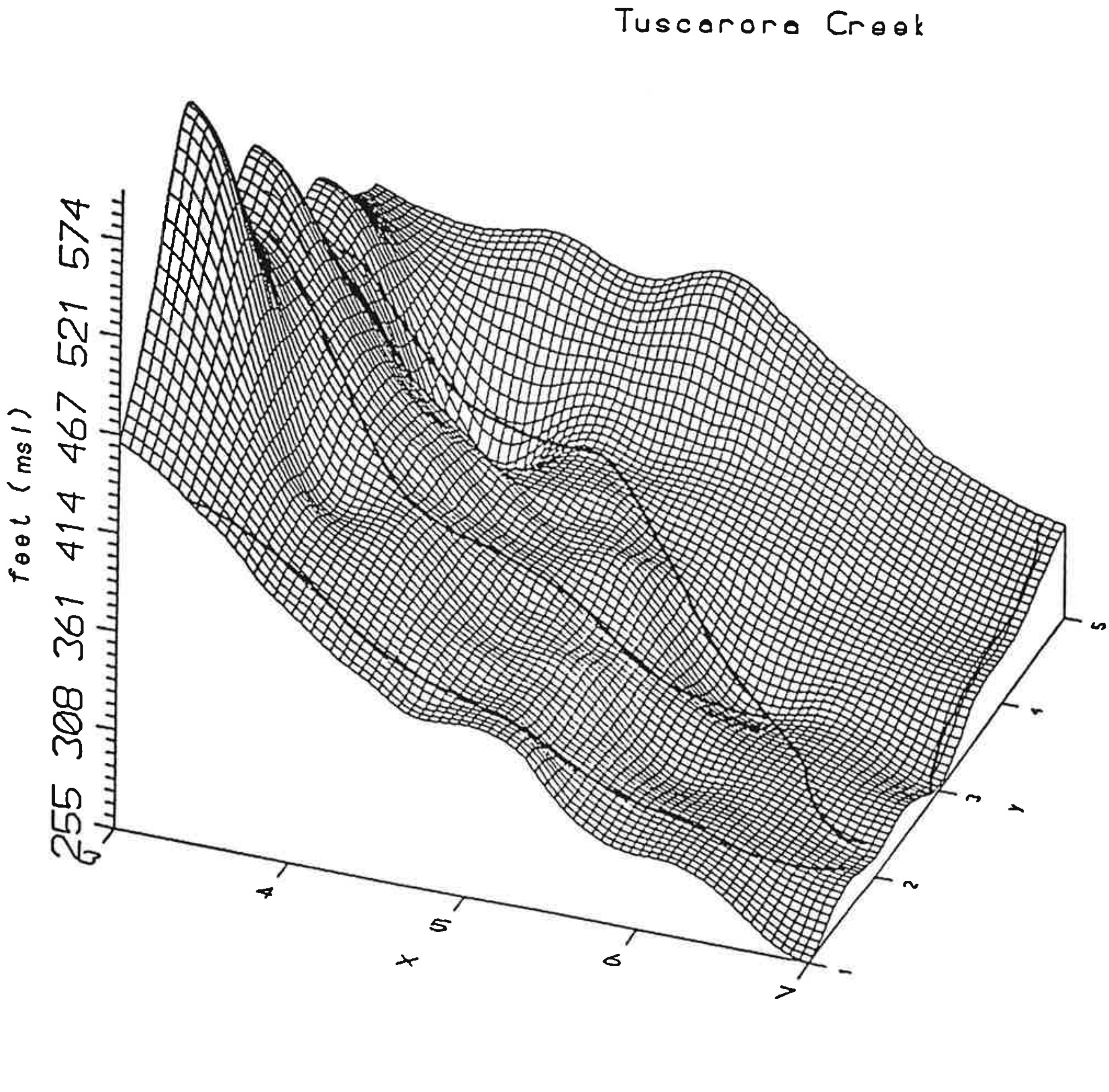


Figure 19. 3-D Potentiometric Surface Map of Tuscarora Creek Basin



FISHING CREEK BASIN

HYDROLOGY

Most subsurface flow is directed towards the east of Fishing Creek basin where Fishing Creek empties into the Monocacy (Figures 20 and 21). This basin had a fairly low number of data points (indicated on the map by "*"). In particular, the western part of the basin is completely without data (in the Catoctin Mountains). The highest reported ground water elevation was 650 feet above mean sea level (at grid location (3,2)), but the land elevation reaches to 1800 feet in the extreme northwest mountains. Therefore the hydraulic gradient cannot be calculated from the data in the western part of the basin and should be estimated by the land elevation at those locations. The major recharge areas can be located where flowlines diverge. The scarce data available in basins such as this one make this type of conclusion much more questionable. However, the Catoctin Mountains could be envisioned as major recharge areas due to land topography alone.

There was only one spring identified in this basin. Water level changes were monitored in two wells in this basin. These two wells are in the lowlands and are fairly close to the surface. They do not exhibit any major changes in water levels (Table 15).

Table 15. WATER LEVEL CHANGES IN FISHING CREEK WELLS

Grid Location (miles)	Low Level (elevated feet)	High Level (elevated feet)	Change (feet)	Land Surface (elev.feet)
(5,3)	390	392	2	400
(4,2)	519	524	5	530

WATER QUALITY

The ground water quality data were very limited in this basin and are listed in Table 16.

Table 16. NITROGEN and PHOSPHORUS CONCENTRATIONS FISHING CREEK WELLS

Location	Nitrogen (mg/l)	Ortho-Phosphorus (mg/l-P)	Depth (feet below land)
A	2.4 (NO_2+NO_3)	0.05	24
B	4.0 (NO_3)	-	28
C	2.6 (NO_2+NO_3)	0.05	46

"-" indicates missing data

Figure 20. Potentiometric Surface of Fishing Creek Basin

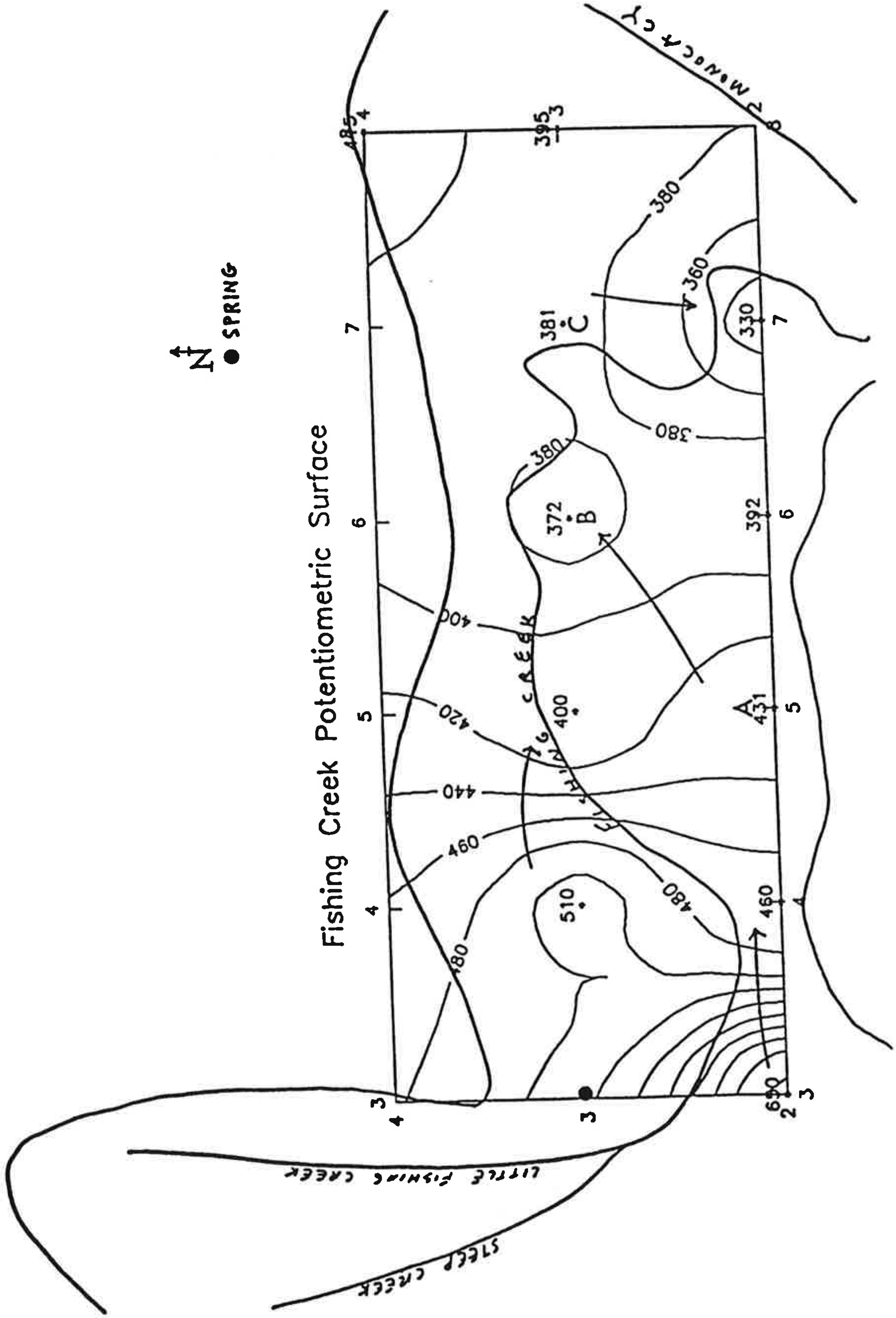
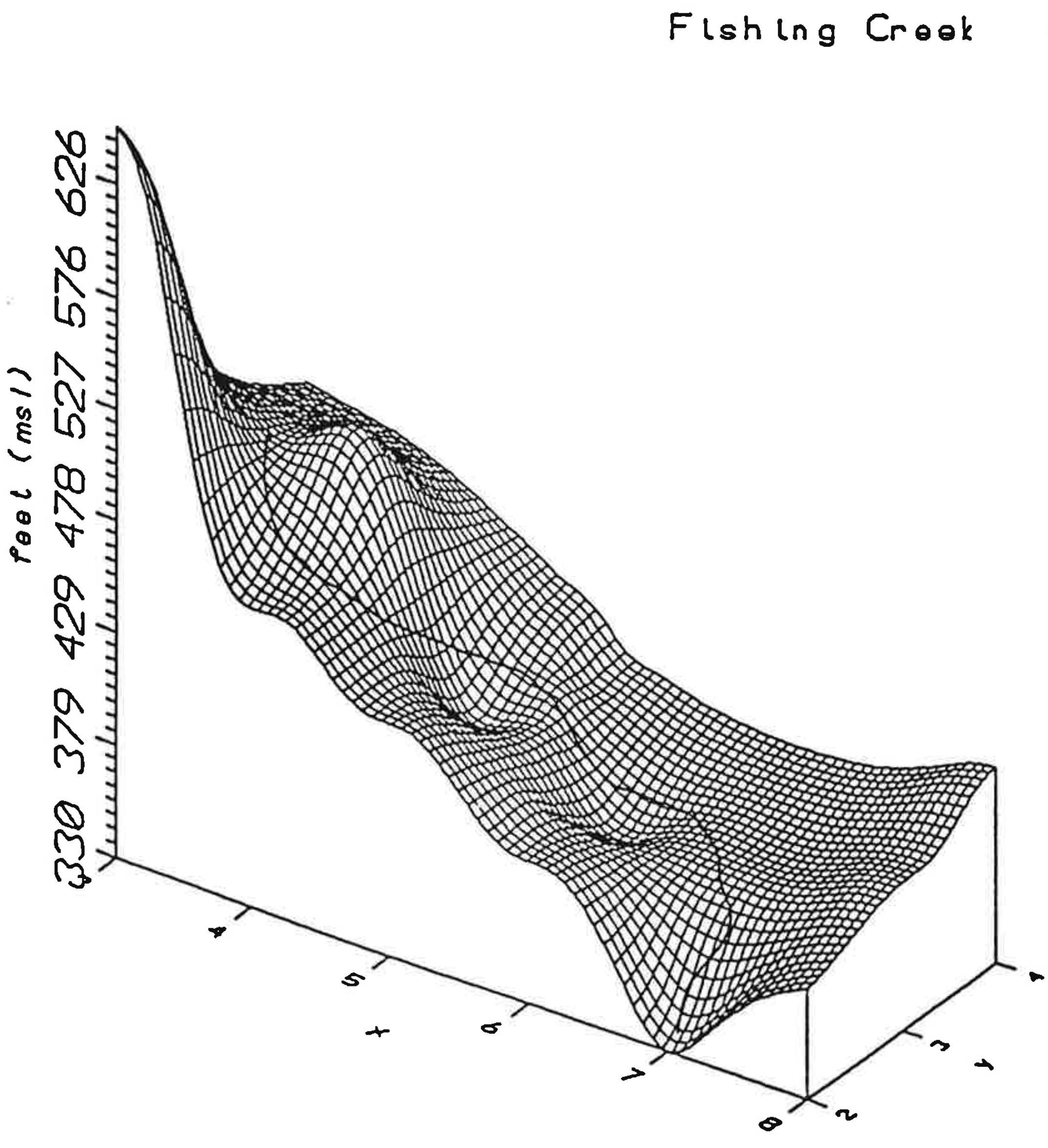


Figure 21. 3-D Potentiometric Surface Map of Fishing Creek Basin



HUNTING CREEK BASIN

HYDROLOGY

Most ground water flow is directed towards the southeast of Hunting Creek basin towards Hunting Creek's outfall (Figures 22 and 23). The most striking characteristics of this basin are the large changes in elevation that occur between the western mountains and the eastern Monocacy valley. The potentiometric surface contour map (Figure 23) reflects this nicely. The ground water hydraulic gradient must be estimated with caution in basins like this. If the gradient is estimated by taking the highest potential point and the lowest potential point found in the basin, the gradient may differ drastically from an estimate based on a smaller area such as a pervious land segment.

There were some data on the discharge rates of these springs, but there was no significant difference in the measurements. The rates ranged from 1 to 20 gallons per minute with a median value of 10.

Water level changes were monitored in six wells in this basin. The ranges in water levels found in this basin are much higher than those found in the basins on the eastern side of the Monocacy. This means that the thickness of the unsaturated zone can be expected to increase during low flow periods and decrease during high flow periods more than in the eastern basins.

Table 17. WATER LEVEL CHANGES IN HUNTING CREEK WELLS

Grid Location (miles)	Low Level (elevated feet)	High Level (elevated feet)	Change (feet)	Land Surface (elev.feet)
(7,6)	597	623	26	630
(6,8)	1147	1150	3	1150
(4,8)	1548	1566	18	1580
(5,7)	1105	1141	36	1150
(6,4)	604	629	25	630
(8,6)	441	466	25	468

WATER QUALITY

The ground water quality data show that nitrite + nitrate nitrogen levels are fairly low (relative to wells from other basins). Phosphorus (Ortho) was measured in many of the observation wells and the numbers seem high in this basin (Table 18).

Table 18. NITROGEN and PHOSPHORUS CONCENTRATIONS HUNTING CREEK WELLS

Location	Nitrogen (mg/l)	Ortho Phosphorus (mg/l-P)	Depth (feet below land
A	2.5 (NO_2+NO_3)	0.03	27
B	0.09 "	0.04	-
C	0.23 "	0.12	-
D	2.9 "	0.02	-
E	1.0 "	0.04	10
F	4.3 "	-	-
G	4.0 (NO_3)	-	27
H	4.1 "	-	25
I	1.9 "	-	65
J	3.0 "	-	65
K	2.8 (NO_2+NO_3)	0.07	34

"-" indicates missing data

Figure 22. Potentiometric Surface of Hunting Creek Basin

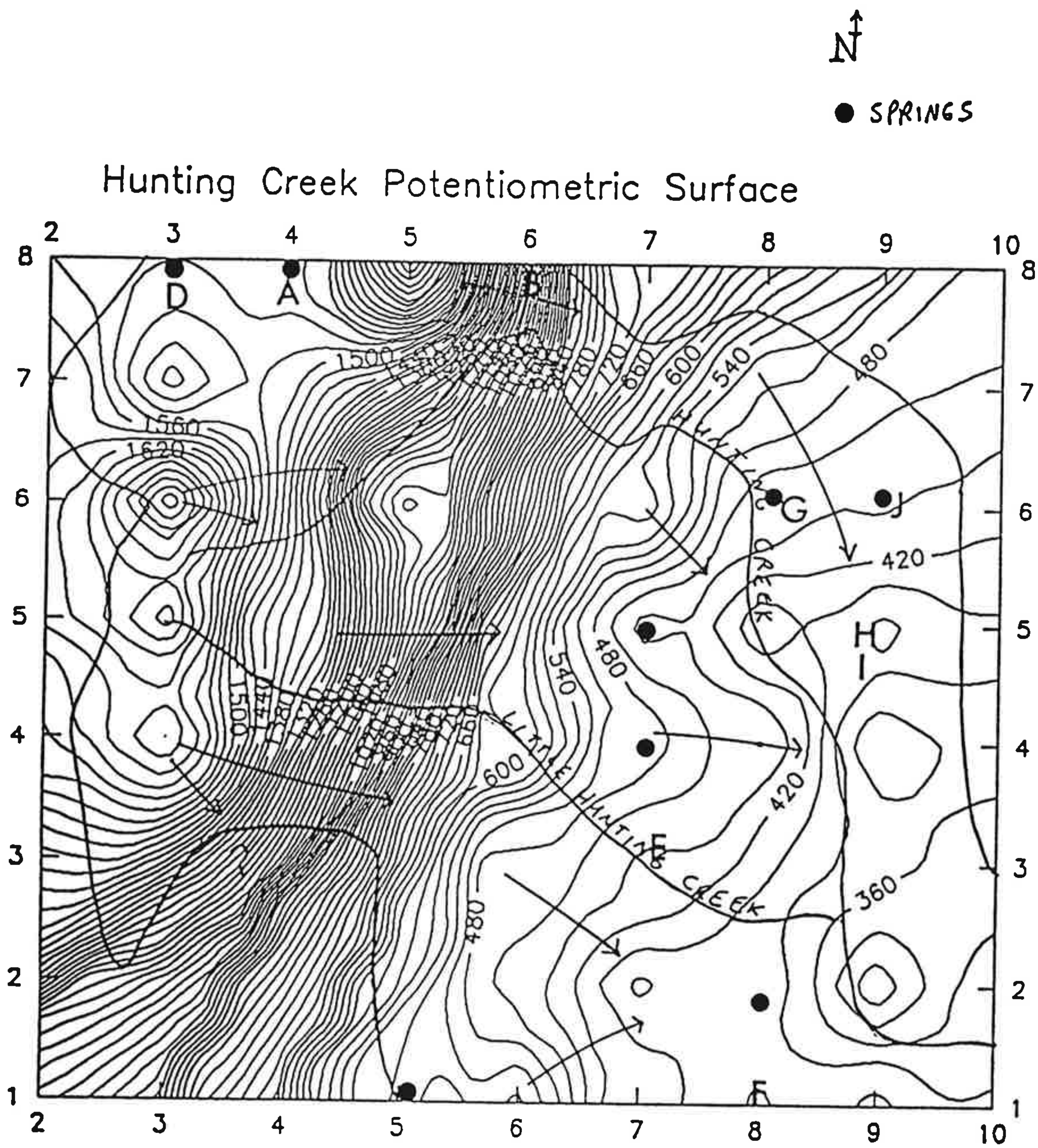
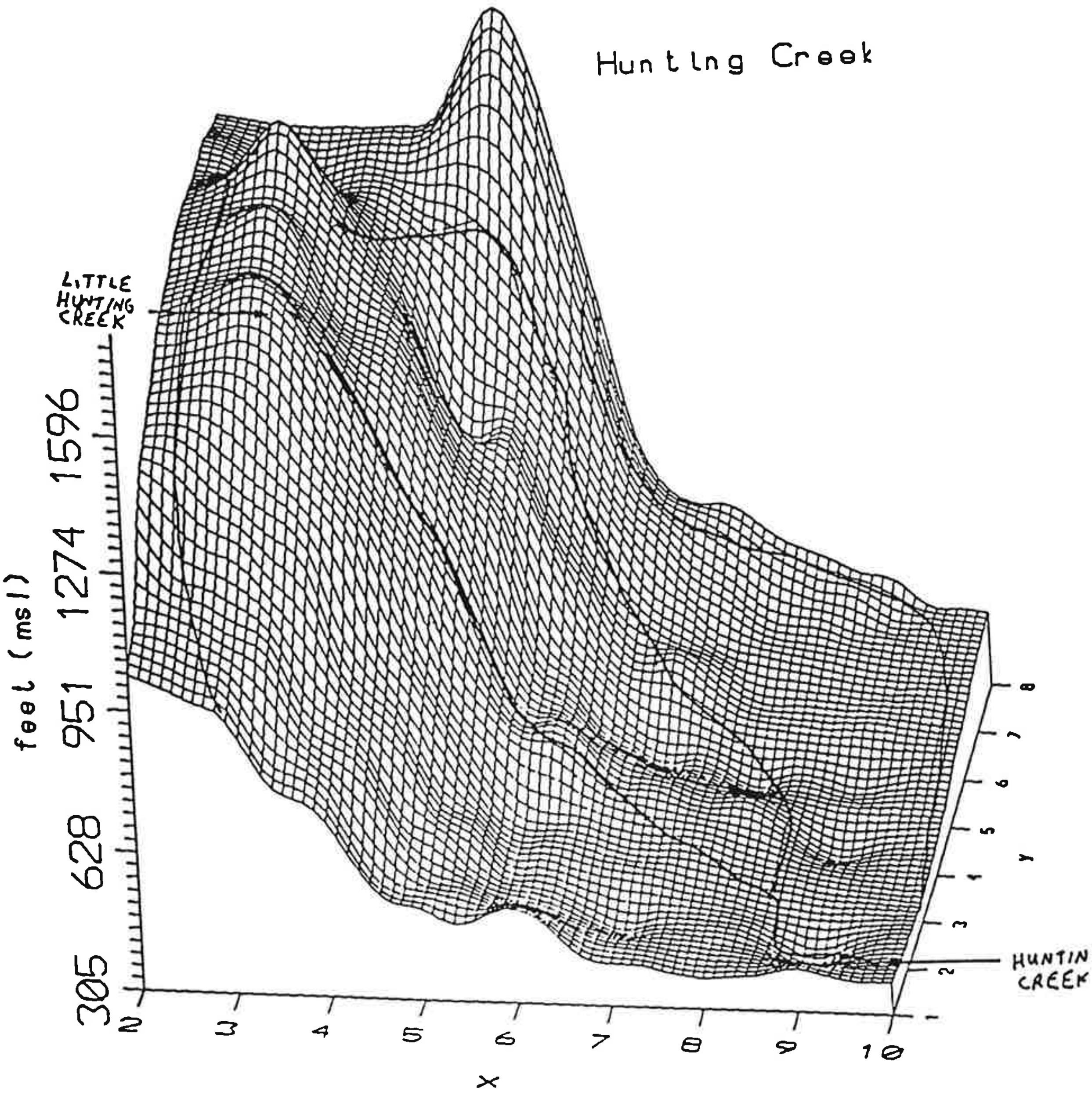


Figure 23. 3-D Potentiometric Surface Map of Hunting Creek Basin



OWENS CREEK BASIN

HYDROLOGY

The ground water flow lines indicate that most flow is directed towards the southeast of the sub-basin towards the confluence of the Monocacy River and Owens Creek (Figures 24 and 25). There were several springs listed for this sub-basin. This is a little surprising because the only other areas with a comparable number of springs were in the limestone valleys.

Springs that are not associated with karst topography can be caused by several geologic conditions. The large number of springs found in this area are probably "fault" or "fracture" springs. These springs occur in jointed or permeable fault zones in low-permeability rock. Ground water movement in these areas is primarily through fractures. The "fracture" springs can form where these fractures intersect the land surface. A "fault" spring may occur where an impermeable faulted rock unit creates a regional boundary to ground water movement and forces water in the aquifer to discharge to the land surface.

The springs found in this basin had fairly low discharge rates, ranging from 0.5 gallons per minute to 20 gallons per minute, but most were around 5 gallons per minute.

Most of the wells used for this sub-basin report were located in the lowlands. (This is generally true for most sub-basins because these areas tend to have the highest well yields, and more wells are drilled there. Also residential construction is concentrated there.) This can be seen very clearly on the 3-D Potentiometric Surface (Figure 25) where the actual data are plotted. The lack of data in the mountains tends to create areas where large mountainous sections get smoothed out (see Piney Mountain).

In other basins the wells located in the higher elevations tended to have more of a range in water level fluctuation than the lower lying ones. In this basin the opposite was found to be true. A well that was located at 1020 feet above sea level (cell 3,7) only fluctuated about one and a half feet, whereas a well found at 518 feet (cell 8,6) fluctuated about 20 feet. The higher elevation well was in an area where the water table was very shallow (about 5 feet), but the lower well was in an area where the ground water was much deeper (44 to 64 feet deep).

WATER QUALITY

Ground water quality data were fairly abundant in this basin. The nitrogen levels are relatively low, however the phosphorus concentrations are among the highest found in this study (Table 19).

Table 19. NITROGEN and PHOSPHORUS CONCENTRATION OWENS CREEK WELLS

Location	Nitrogen (mg/l)		Ortho Phosphorus (mg/l-P)	Depth (feet below land
A	1.4	(NO_2+NO_3)	0.09	-
B	1.4	"	0.06	52
C	0.4	"	0.03	28
D		"		
E	1.2	"	0.06	-
F	5.9	(NO_3)	-	30
G	0.5	"	-	14
H	1.4	"	-	-
I	1.2	(NO_2+NO_3)	0.03	-
J	8.5	(NO_3)	-	38
K	0.3	(NO_2+NO_3)	0.04	10

"-" indicates missing data

Figure 24. Potentiometric Surface of Owens Creek Basin

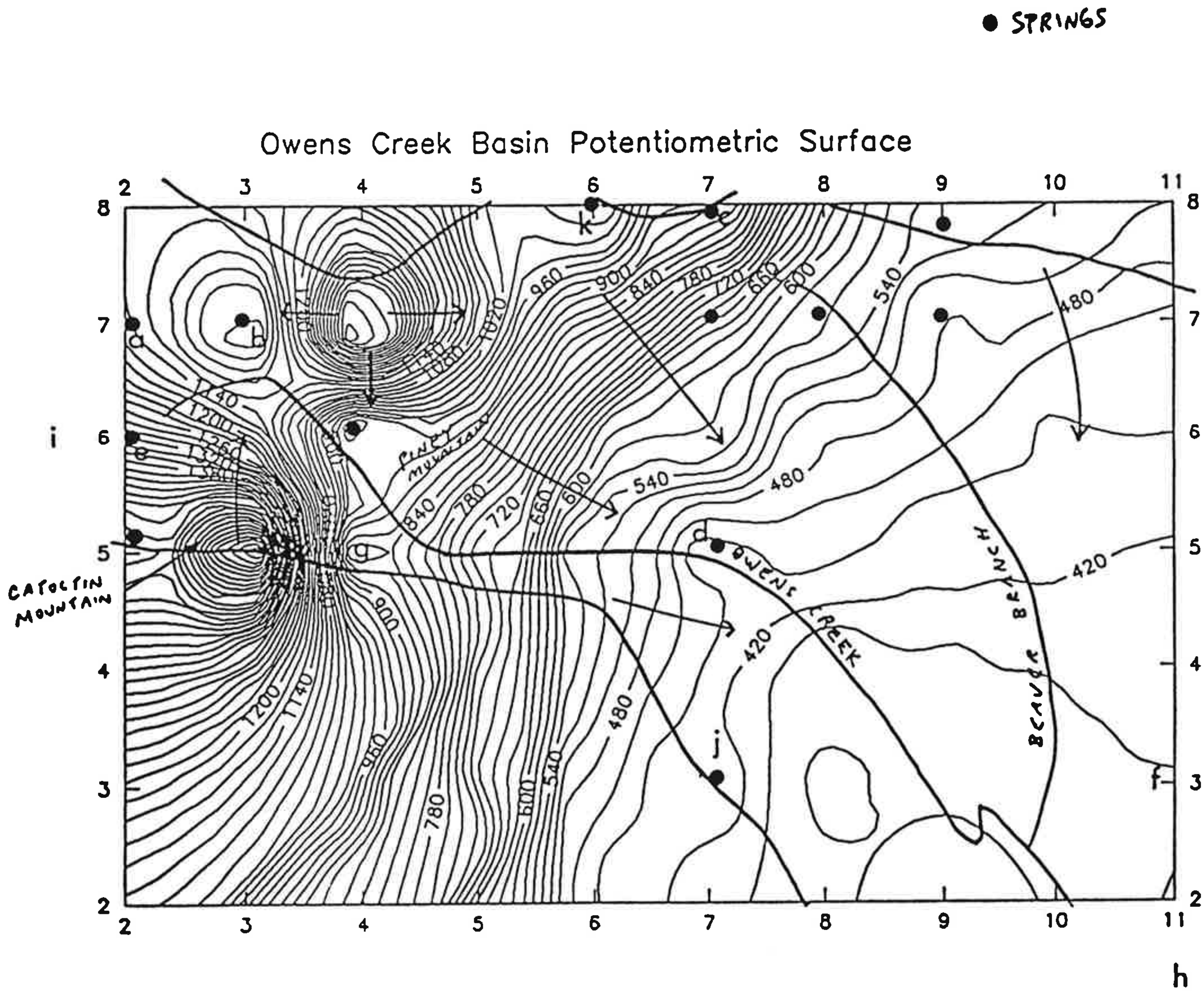
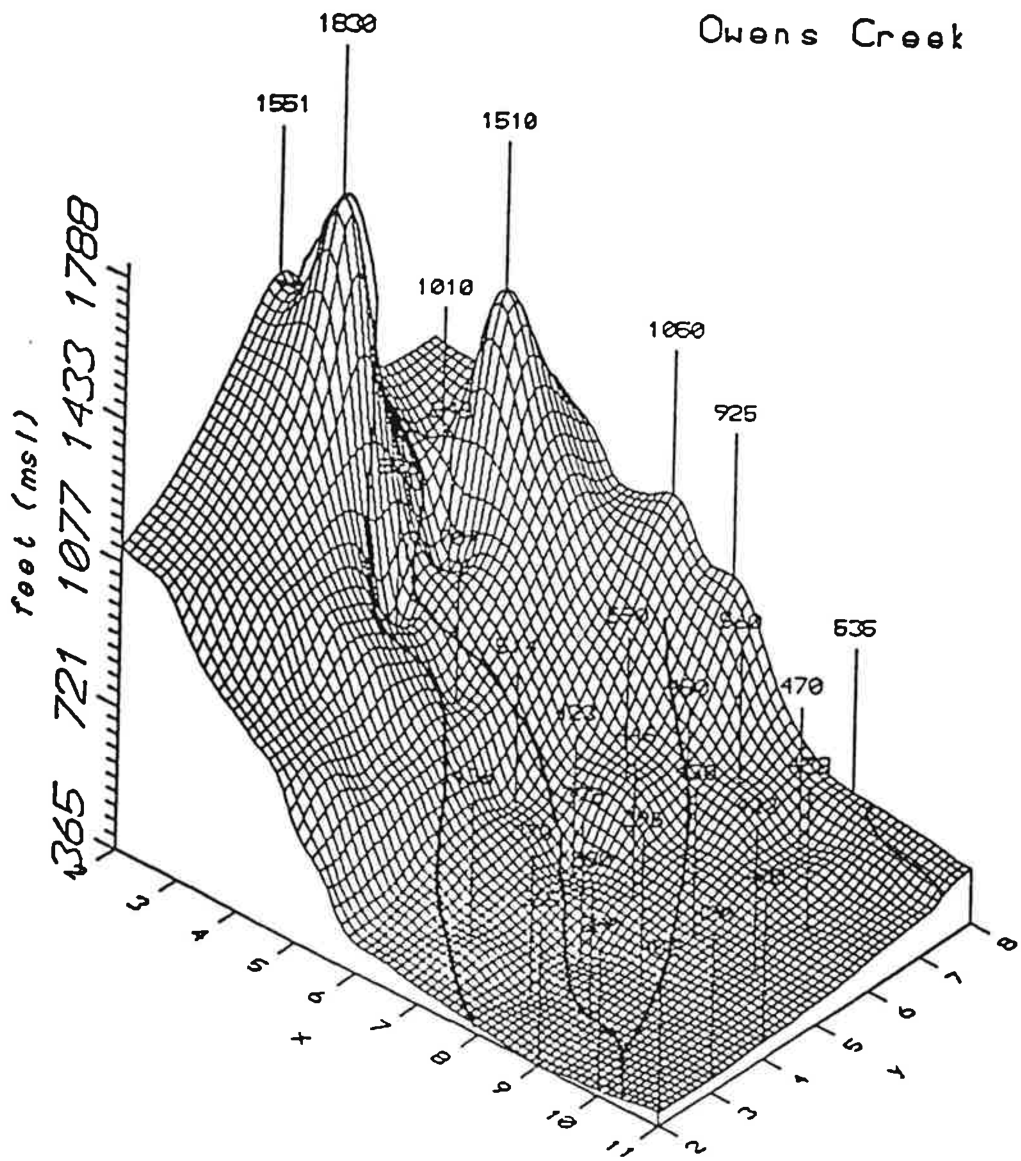


Figure 25. 3-D Potentiometric Surface Map of Owens Creek Basin



TOMS CREEK BASIN

HYDROLOGY

Most ground water flow is directed towards Toms Creek and the Monocacy River (Figures 26 and 17). The direction of flows deviates from this overall pattern locally, but it seems that the surface water basin and the ground water basin correspond fairly well in this area. A large part of the northwest corner of the basin is not drawn in the contour map due to lack of data in that area. Data are indicated on the map by "*". Jacks Mountain is located around (4,8) and (5,9) and is not shown due to the lack of well data there. The regional flow line extends from the western edge of the basin under Jacks Mountain towards Toms Creek. The elevations at Jacks Mountain are around 1500 feet but the ground water levels are interpolated at around 700 feet. These interpolations are too low for the area directly below Jacks Mountain, but the flow lines are a reasonable indication of the regional paths.

There were six springs identified by the data sources used for this investigation. These springs were concentrated in the southern parts of the basin. The largest ranges in water level elevation are found in this part of the basin (Table 20). These springs are associated with non-carbonate rock systems. Their yields were low to moderate, and ranged from 4 to 60 gallons per minute.

Of the wells that were measured periodically, the largest range in water levels was in a well located at a topographically low spot. This contradicts the rule of thumb that the largest fluctuations in water levels will be found in upland wells thus emphasizing the fact that these types of generalizations must be applied with caution.

Table 20. WATER LEVEL MEASUREMENTS IN TOMS CREEK WELLS

Grid Location (miles)	Elevation (feet)	(Depth to water) High (feet)	Low (feet)	Difference (feet)
2,5	1030	0.09	11.81	11.7
5,6	655	1.45	8.81	7.4
10,5	385	0.62	3.74	3.1
12,5	425	1.49	19.36	17.9

WATER QUALITY

The ground water quality data were relatively abundant for both nitrogen and phosphorus in this basin. The nitrogen levels seem to be low in all wells except "J", and the phosphorus levels seem to be fairly high in all wells measured except "D".

Table 21. NITROGEN and PHOSPHORUS CONCENTRATIONS TOMS CREEK WELLS

Location	Nitrogen (mg/l)	Phosphorus* (mg/l-P)	Depth (feet below land)
A	2.7 (NO_3)	-	-
B	1.2 (NO_2+NO_3)	0.02	11
C	1.5 "	0.05	52
D	0.1 "	<.01	15
E	0.4 "	0.04	10
F	0.4 "	0.02	28
G	0.5 (NO_3)	-	40
H	1.2 "	-	18
I	<.1 (NO_2+NO_3)	<.01 (Ortho)	18
J	11.0 "	0.05	40
K	2.0 (NO_3)	-	22
L	2.7 "	-	-

"-" indicates missing data

* Total phosphorus unless otherwise indicated.

Figure 26. Potentiometric Surface of Toms Creek Basin

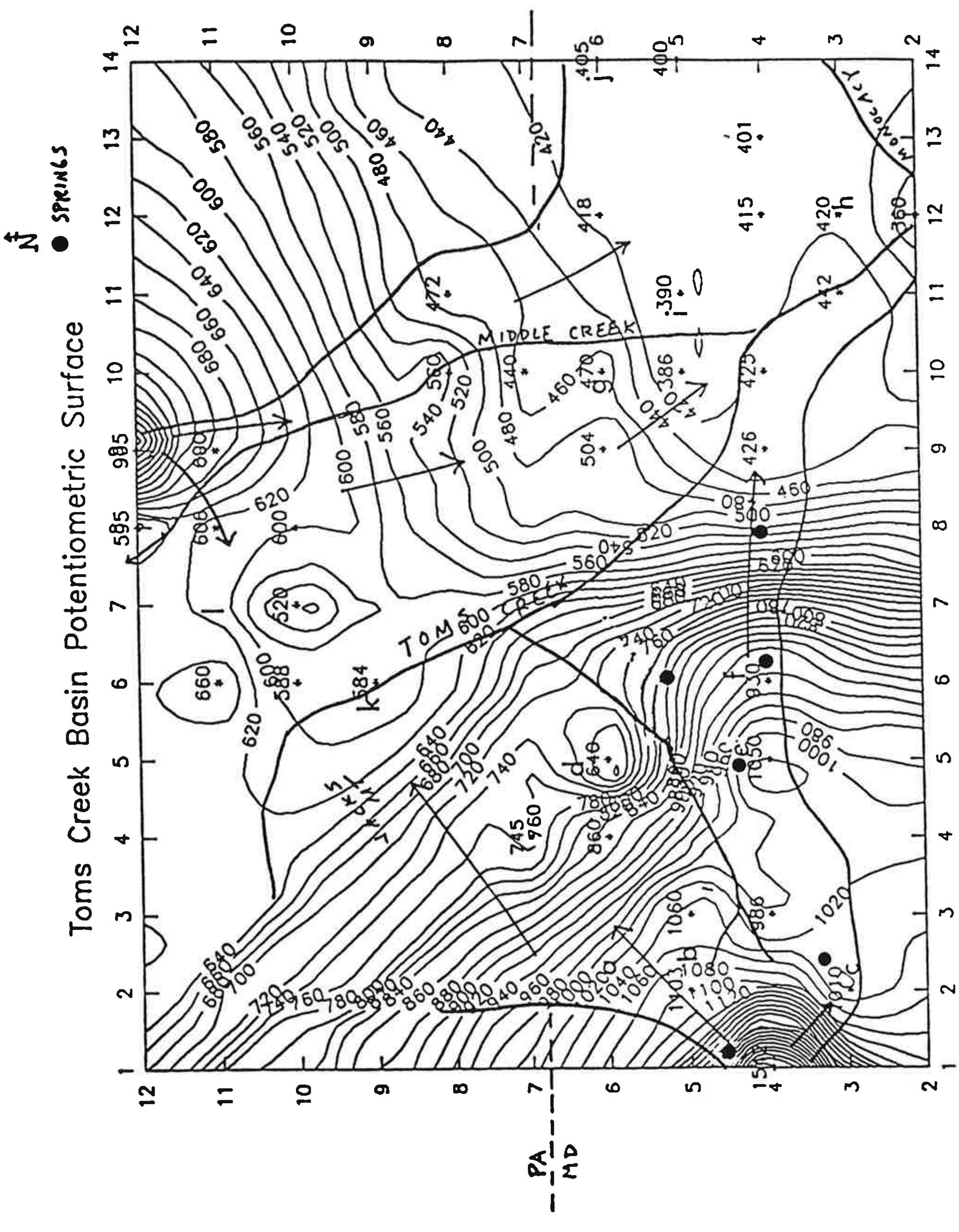
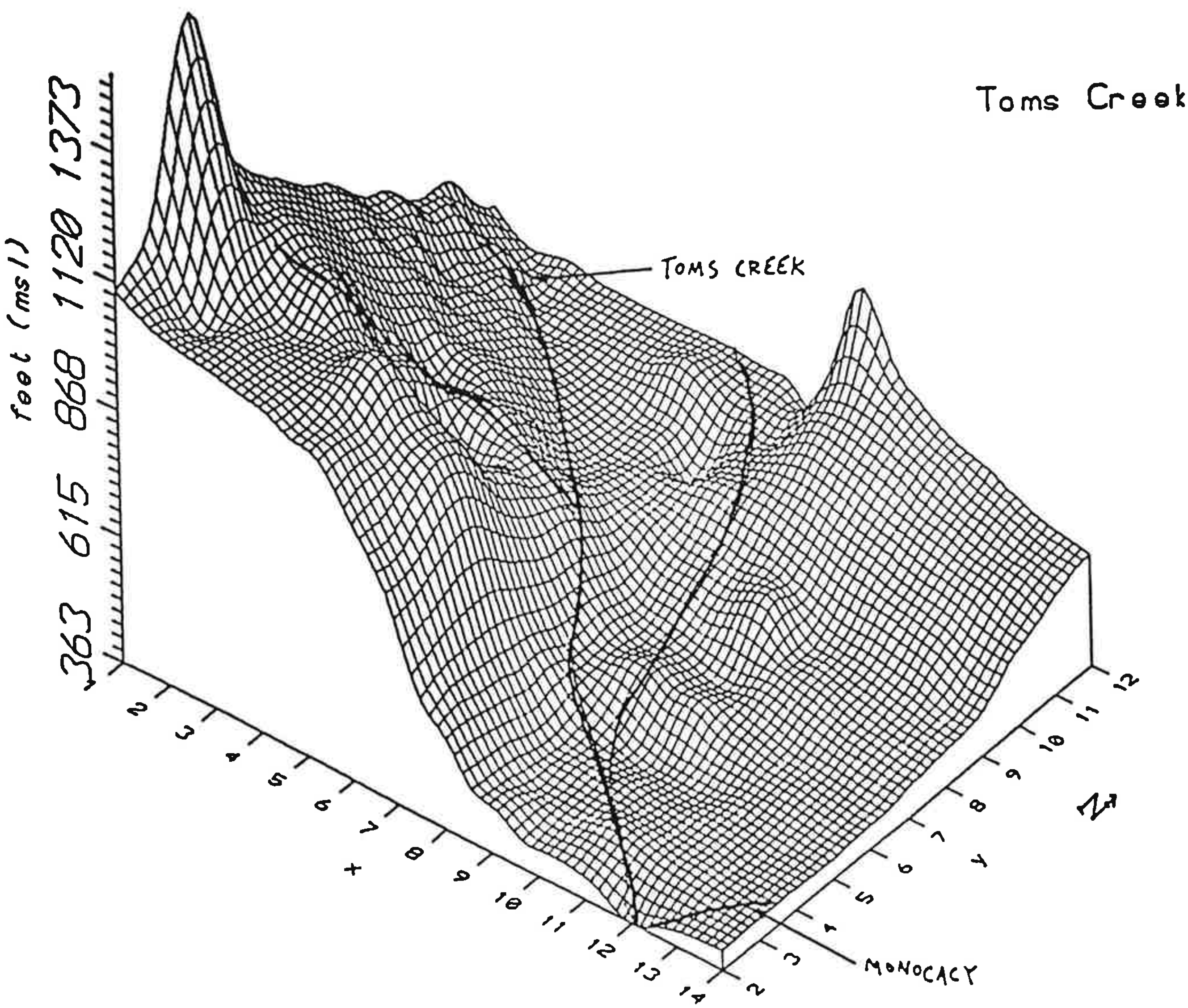


Figure 27. 3-D Potentiometric Surface Map of Toms Creek Basin



MARSH CREEK BASIN

HYDROLOGY

The ground water flow lines indicate that most flow is directed towards the southeast part of the basin where Marsh Creek exits the basin (Figures 28 and 29). Three springs were recorded in this basin and they had low yields (i.e. 3-6 gallons per minute). The water table ranged from an average depth of 66 feet below the surface to 0 feet below the surface, but was mostly around 15-30 feet deep.

The spring that was located in cell (1,9) was used as a datum in generating the potentiometric surface. This cell is located very near South Mountain and thus is of high elevation. The absolute values of the water elevations that are extrapolated to nearby cells (i.e. those without data) may have fairly large errors.

The depth to water did not show any major patterns (except the shallowness mentioned above) and the rule of thumb used for the Maryland basins can be applied here (i.e. deeper in the highlands and more shallow in the lowlands).

Water table elevation data for Pennsylvania (taken from Taylor and Royer, 1981) represent measurements made in the 1970's and 1980's, unlike Maryland data, which were available from the 1950's through the 1970's (Hilleary and Weisle, 1981 and Dine et al., 1985).

WATER QUALITY

The ground water quality data were scarce in this basin and were found in only six grid cells. Phosphorus data were completely lacking except for one well. Nitrate nitrogen seems to be low. The nitrogen data were recorded in the 60's, 70's and 80's.

Table 22. NITROGEN and PHOSPHORUS CONCENTRATION MARSH CREEK WELLS

Location	Nitrogen (mg/l)	Total Phosphorus (mg/l-P)	Depth (feet below land)
A	2.0 (NO_3)	-	-
B	0.27 "	-	-
C	0.61 "	-	3
D	0.40 "	-	45
E	0.0 "	-	19
F	3.1 "	0.2	-

"-" indicates missing data

Figure 28. Potentiometric Surface of Marsh Creek

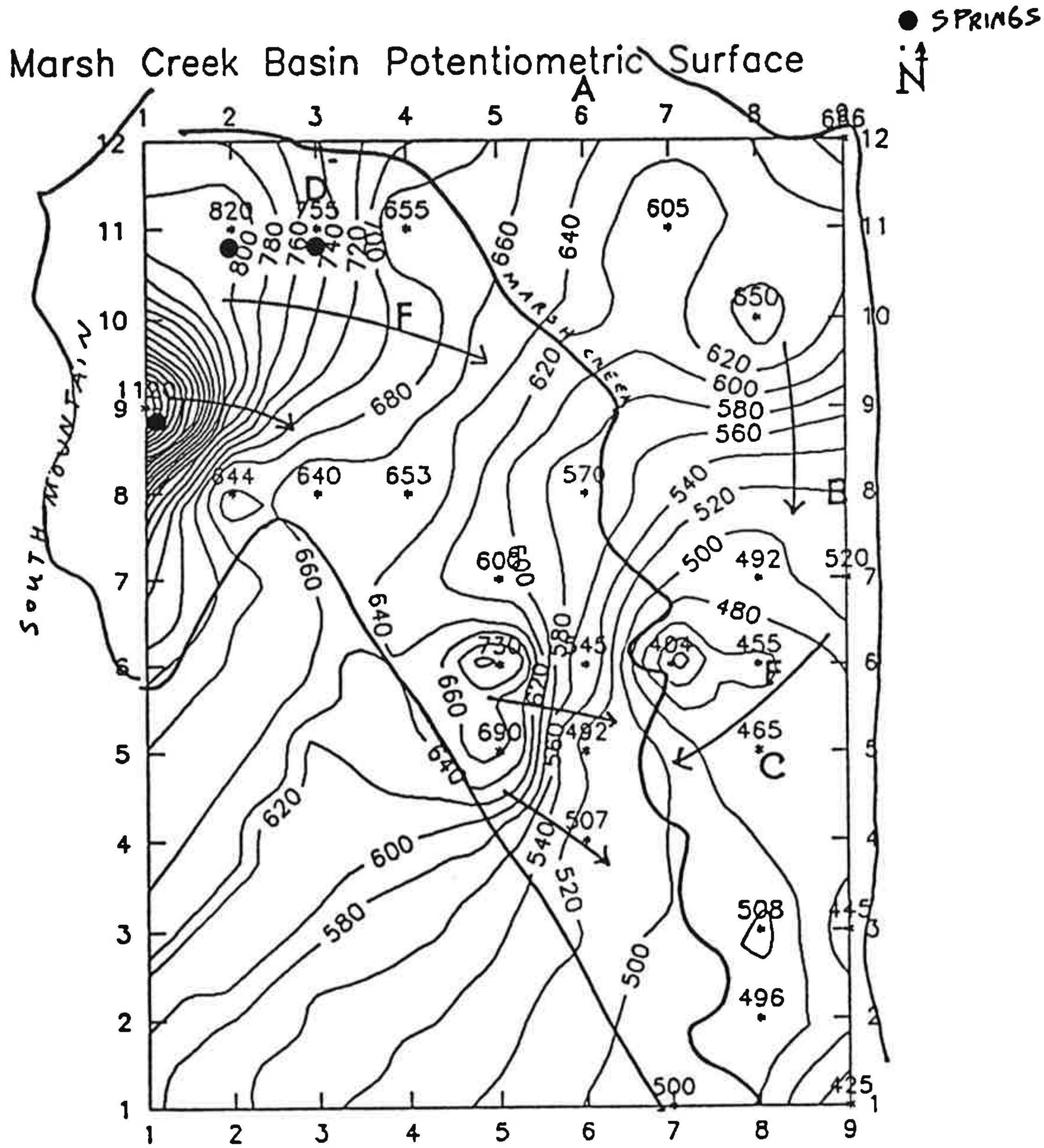
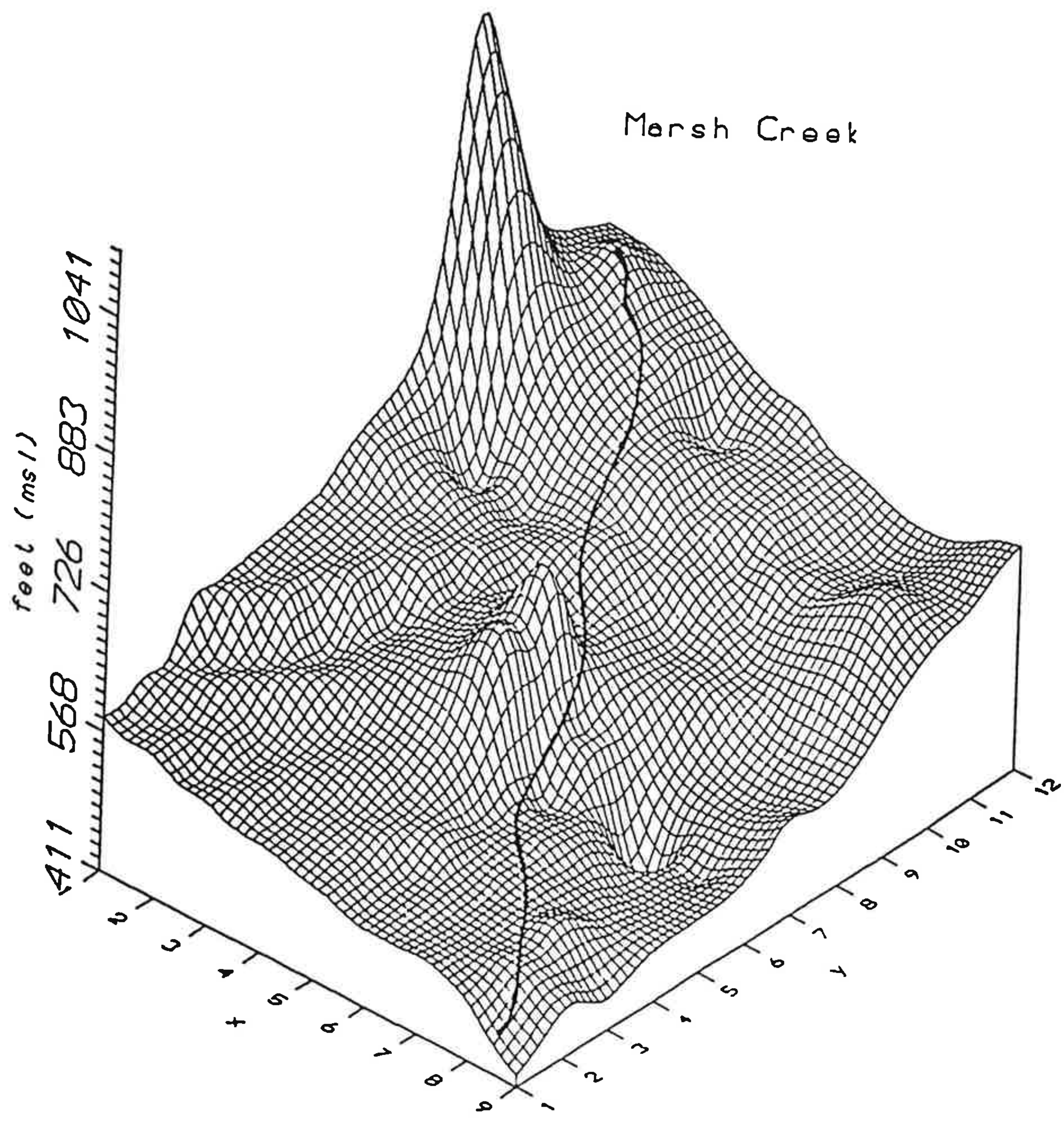


Figure 29. 3-D Potentiometric Surface Map of Marsh Creek Basin



ROCK CREEK BASIN

HYDROLOGY

The ground water flow lines indicate that most flow is directed towards the southwest part of the basin where Rock Creek's valley occurs. There were no springs listed for this basin, but there were two flowing wells (at (7,7) and (2,12)), which indicates that there are confining beds in the area.

WATER QUALITY

The ground water quality data were scarce in this basin and were found in only three grid cells. Phosphorus data were completely lacking for those three wells, but the nitrate nitrogen seems to be fairly low. The nitrogen data were recorded in the 60's and 70's.

Table 23. NITROGEN CONCENTRATIONS ROCK CREEK WELLS

Location	Nitrogen (mg/l)
A	5.0 (NO_3)
B	3.3 "
C	0.5 "

"-" indicates missing data

Figure 30. Potentiometric Surface of Rock Creek Basin

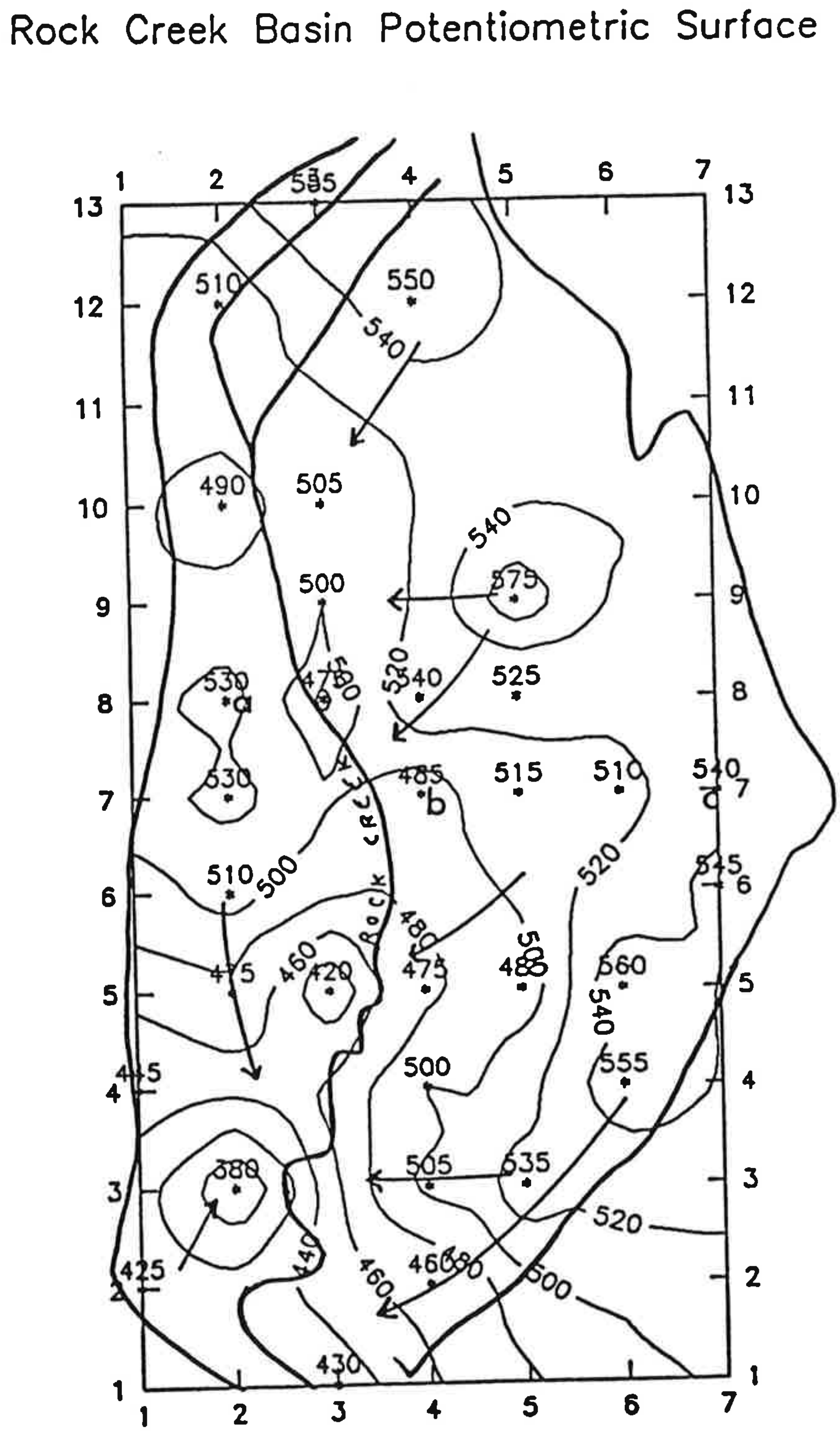
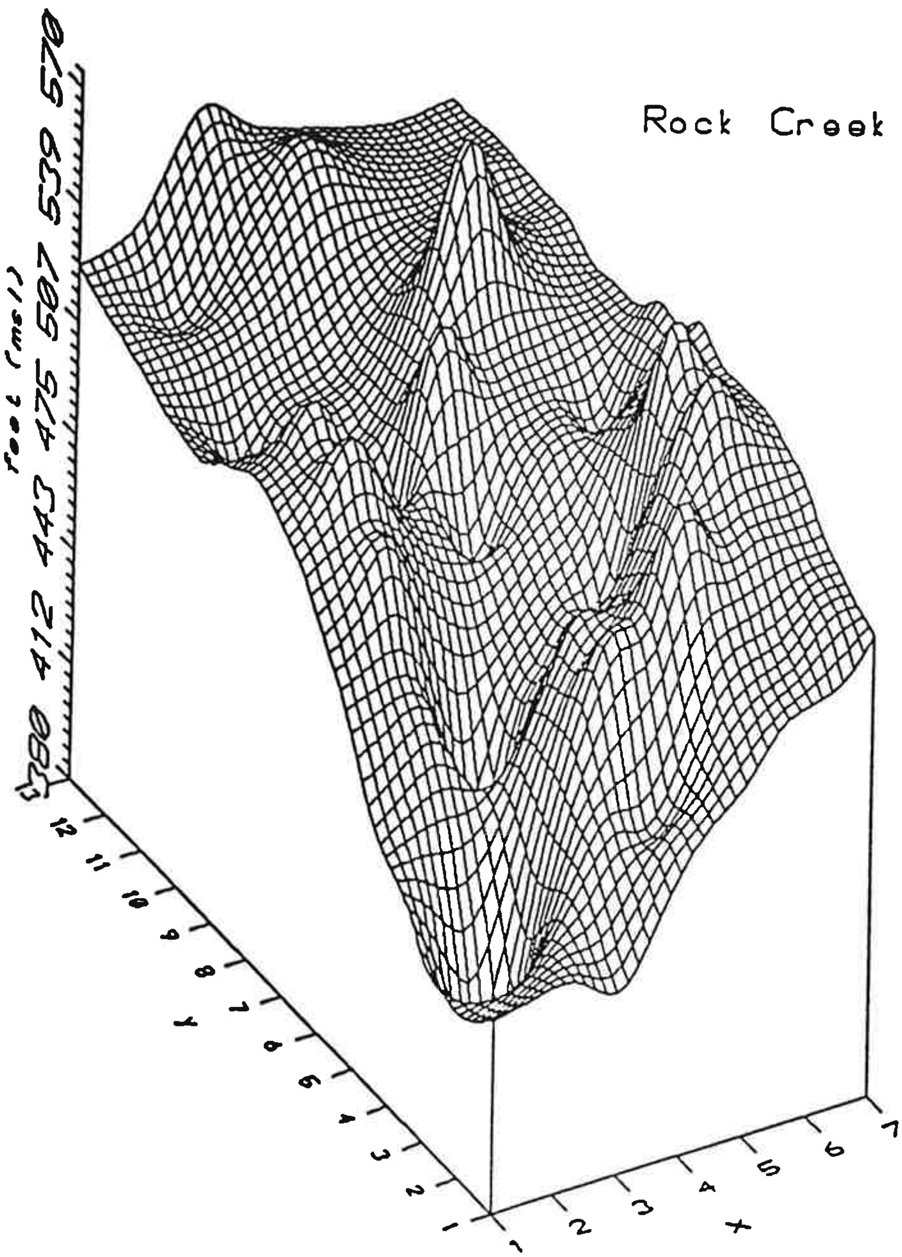


Figure 31. 3-D Potentiometric Surface Map of Rock Creek Basin



ALLOWAY CREEK BASIN

HYDROLOGY

The ground water flow lines indicate that most flow is directed towards the southwest part of the basin where Alloway Creek empties into the Monocacy (figure 32 and 33). No springs were listed for this basin. The water table was consistently fairly shallow in this basin (average depth to water was 24 feet). Most of the measurements were at topographic low spots.

WATER QUALITY

The ground water quality data were very scarce in this basin and were found in only three grid cells. Phosphorus data were completely lacking for those three wells, but the nitrate nitrogen seems to be high. The nitrogen data were collected in the 60's, 70's and 80's.

Table 24. NITROGEN CONCENTRATIONS ALLOWAY CREEK WELLS

Location	Nitrogen (mg/l)	Depth (feet below land)
A	5.0 (NO_3)	40
B	15.0 "	16
C	8.0 "	-

"-" indicates missing data

Figure 32. Potentiometric Surface of Alloway Creek Basin

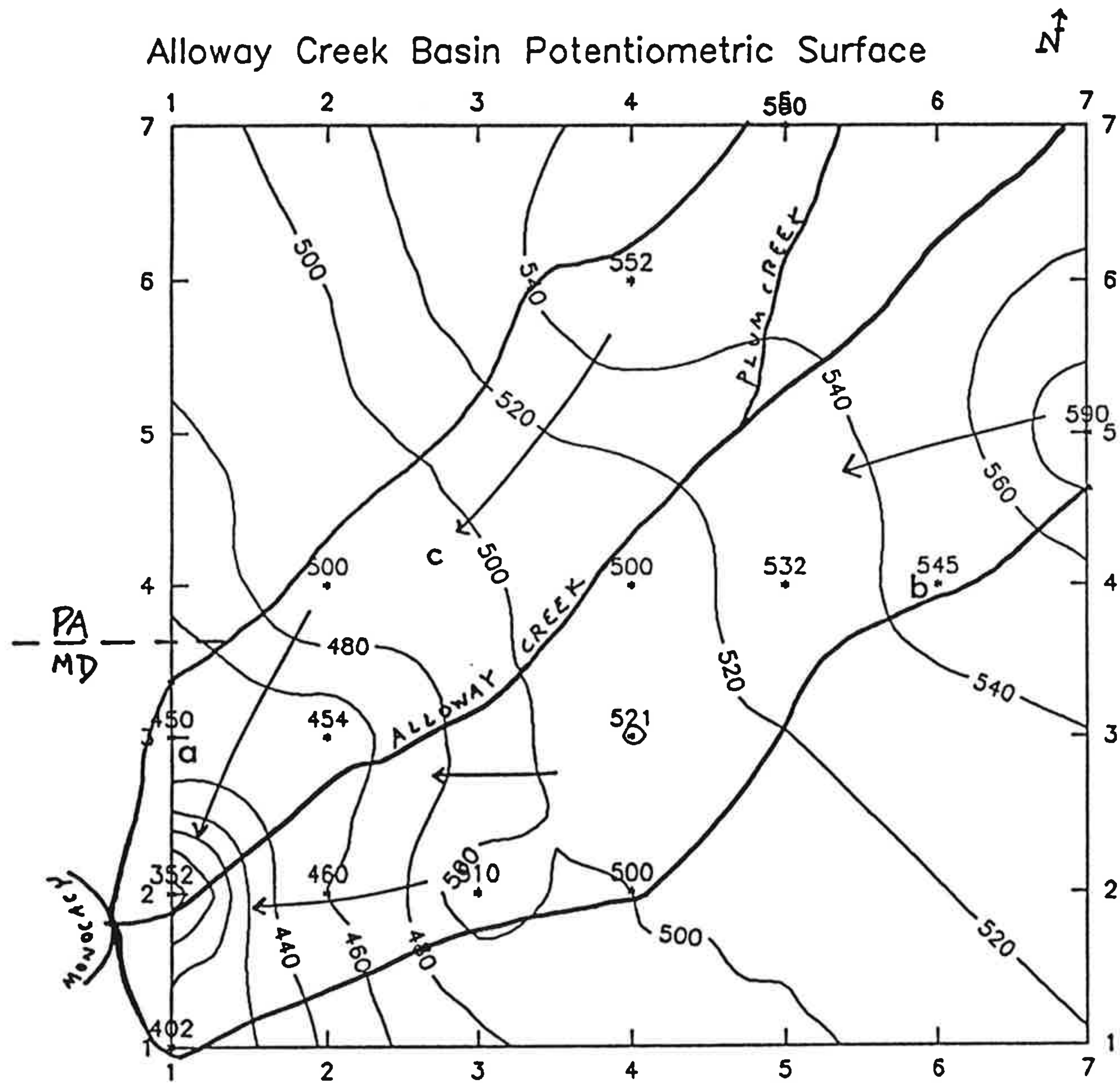
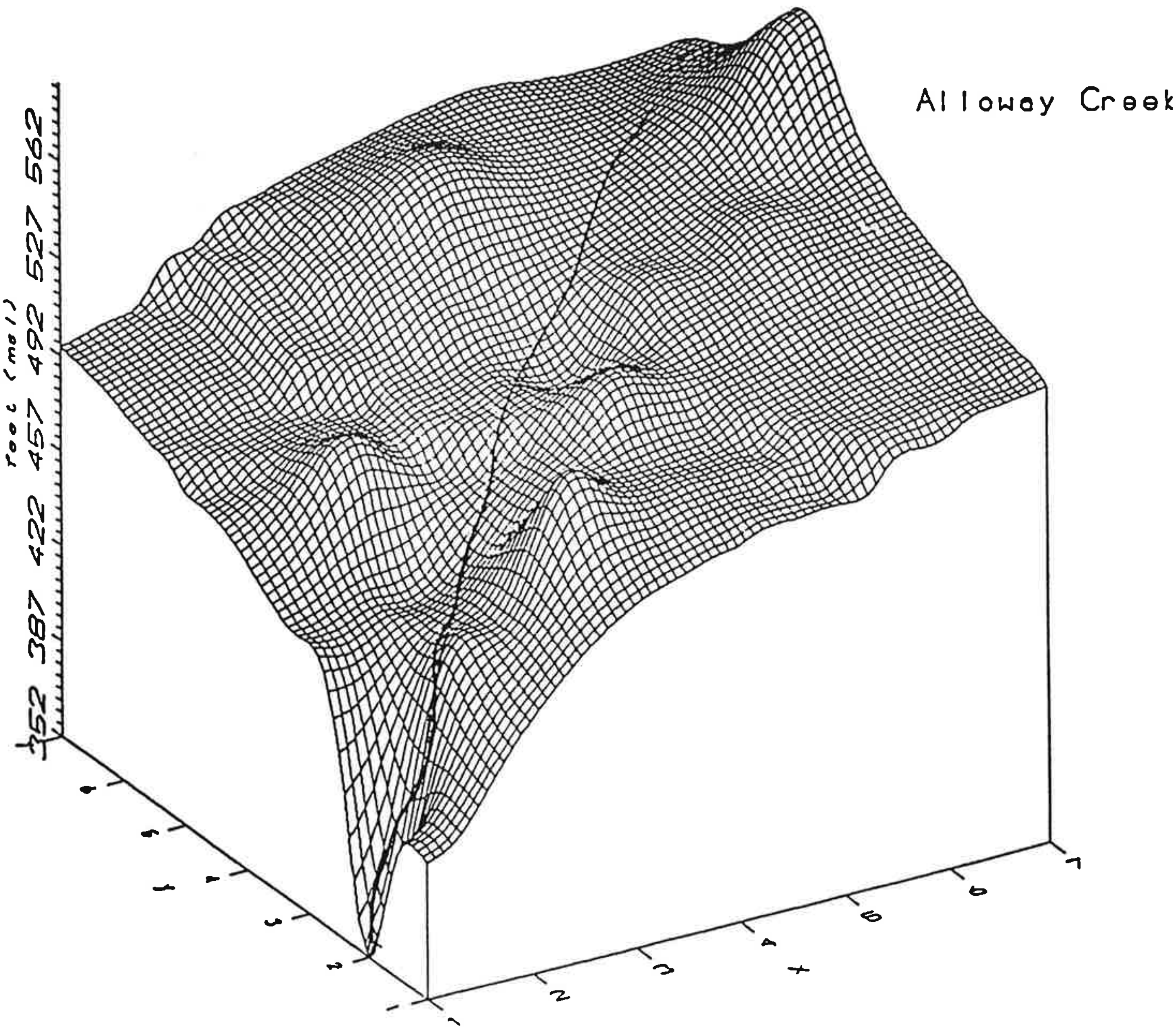


Figure 33. 3-D Potentiometric Surface Map of Alloway Creek Basin



PINEY CREEK BASIN

HYDROLOGY

The ground water flow lines indicate that most flow is directed towards the west part of the sub-basin to the Monocacy River. There were no springs listed for this sub-basin, and water quality data were scarce.

The data on depth to water was fairly abundant in this basin and therefore a dense network of data was available for the contour map (Figures 34 and 35). The depth to water was consistently fairly shallow throughout this basin, the average values for all grid cells ranged from 10 to 45 feet (individual wells ranged from 0 to 70 feet) below land surface.

WATER QUALITY

Table 25. NITROGEN and PHOSPHORUS CONCENTRATION PINEY CREEK WELLS

Location	Nitrogen (mg/l)	Total Phosphorus (mg/l-P)	Depth (feet below land)
A	5.6 (NO_3)	-	23
B	3.6 "	0.03	-

"-" indicates missing data

Figure 34. Potentiometric Surface of Piney Creek Basin

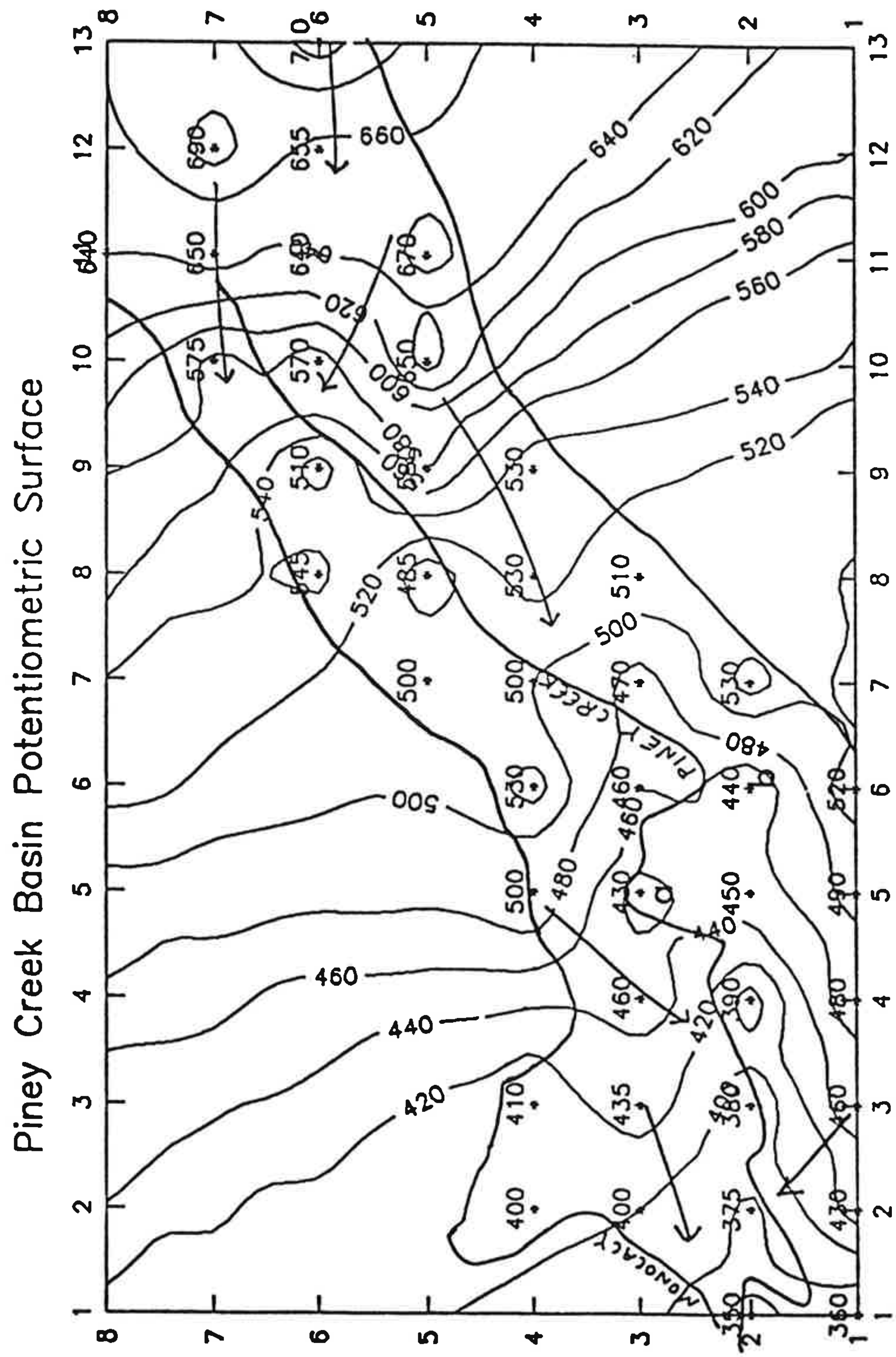


Figure 35. 3-D Potentiometric Surface Map of Piney Creek Basin

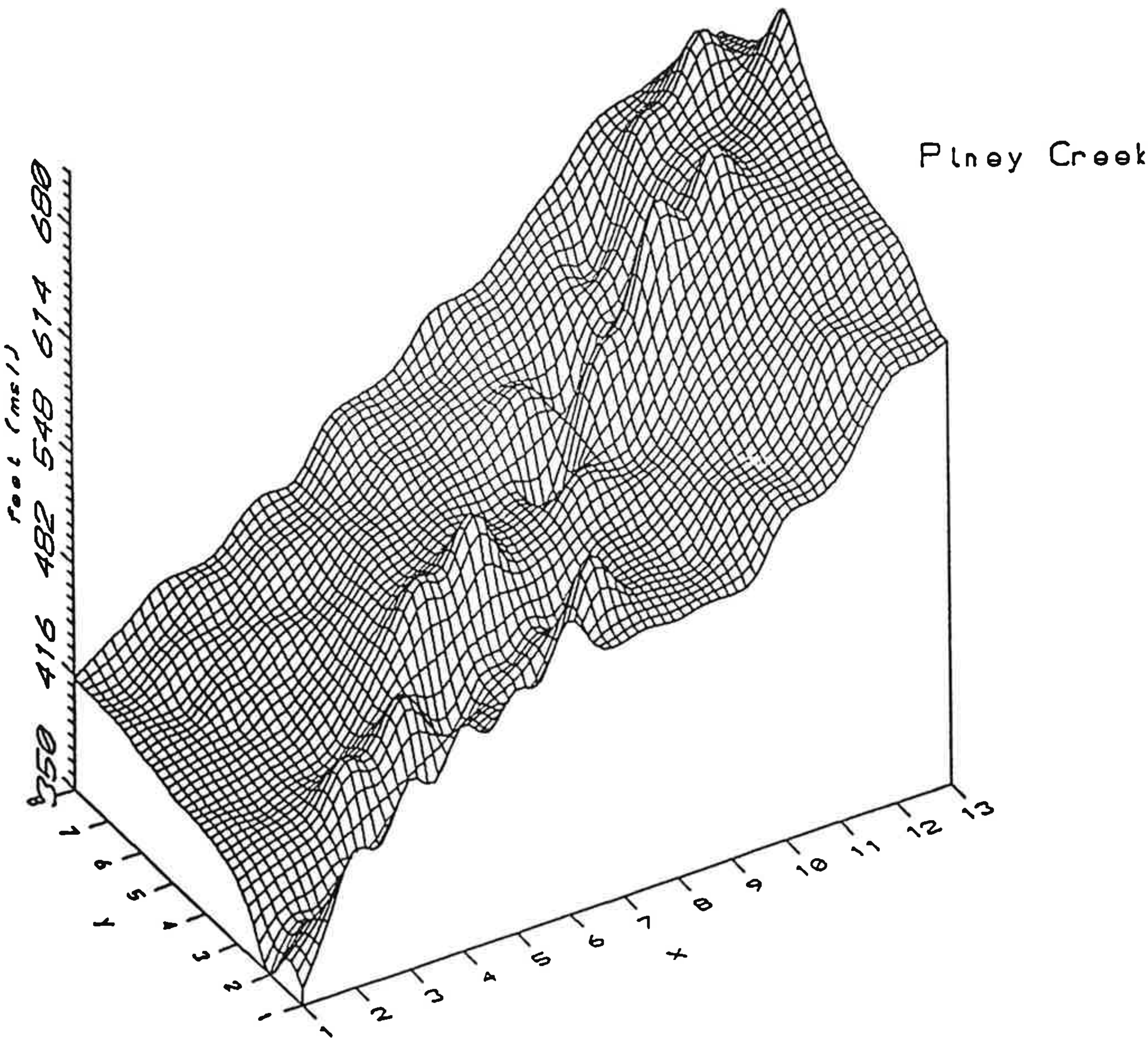


Figure 36. Monocacy River Basin Location Map

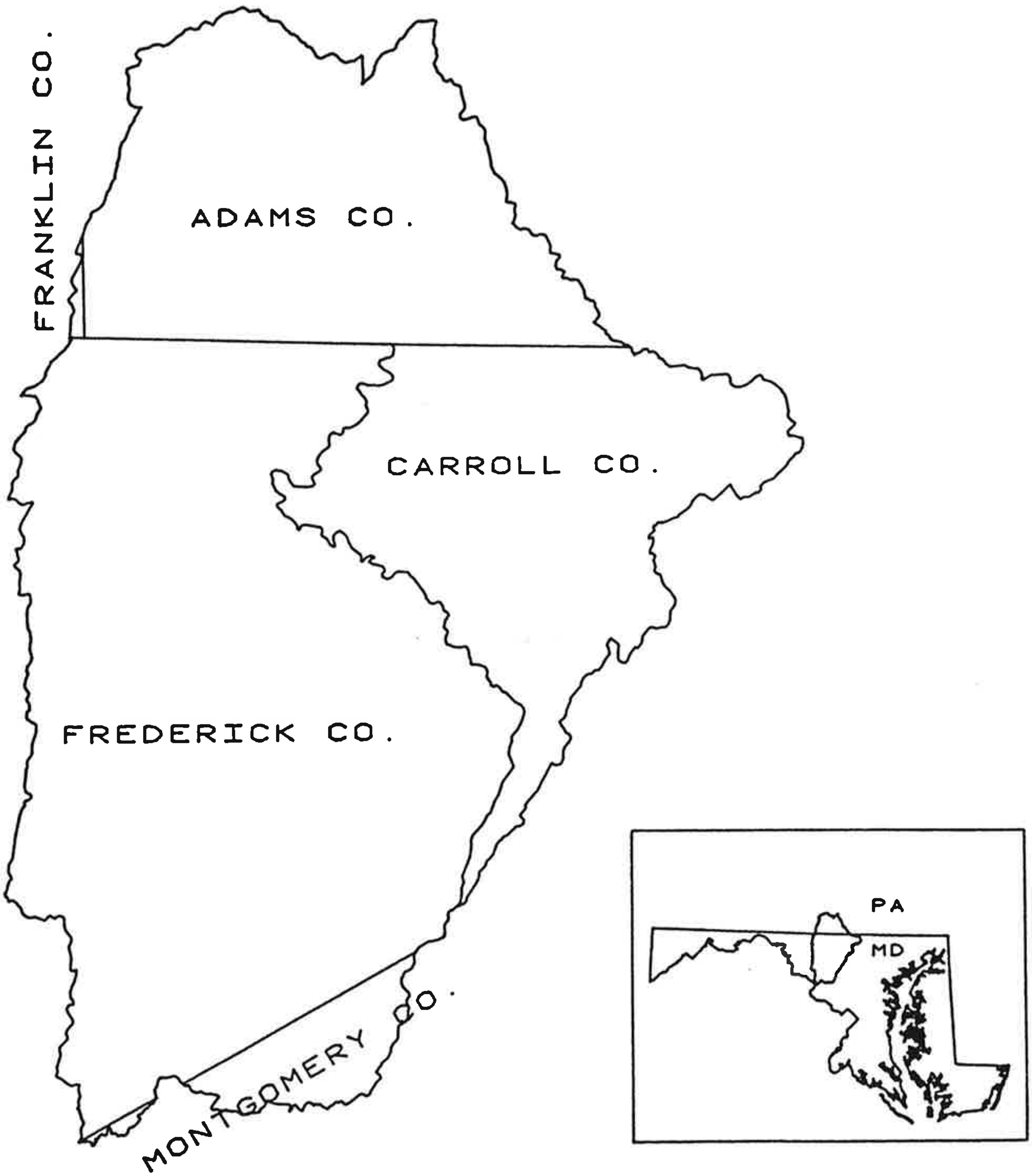
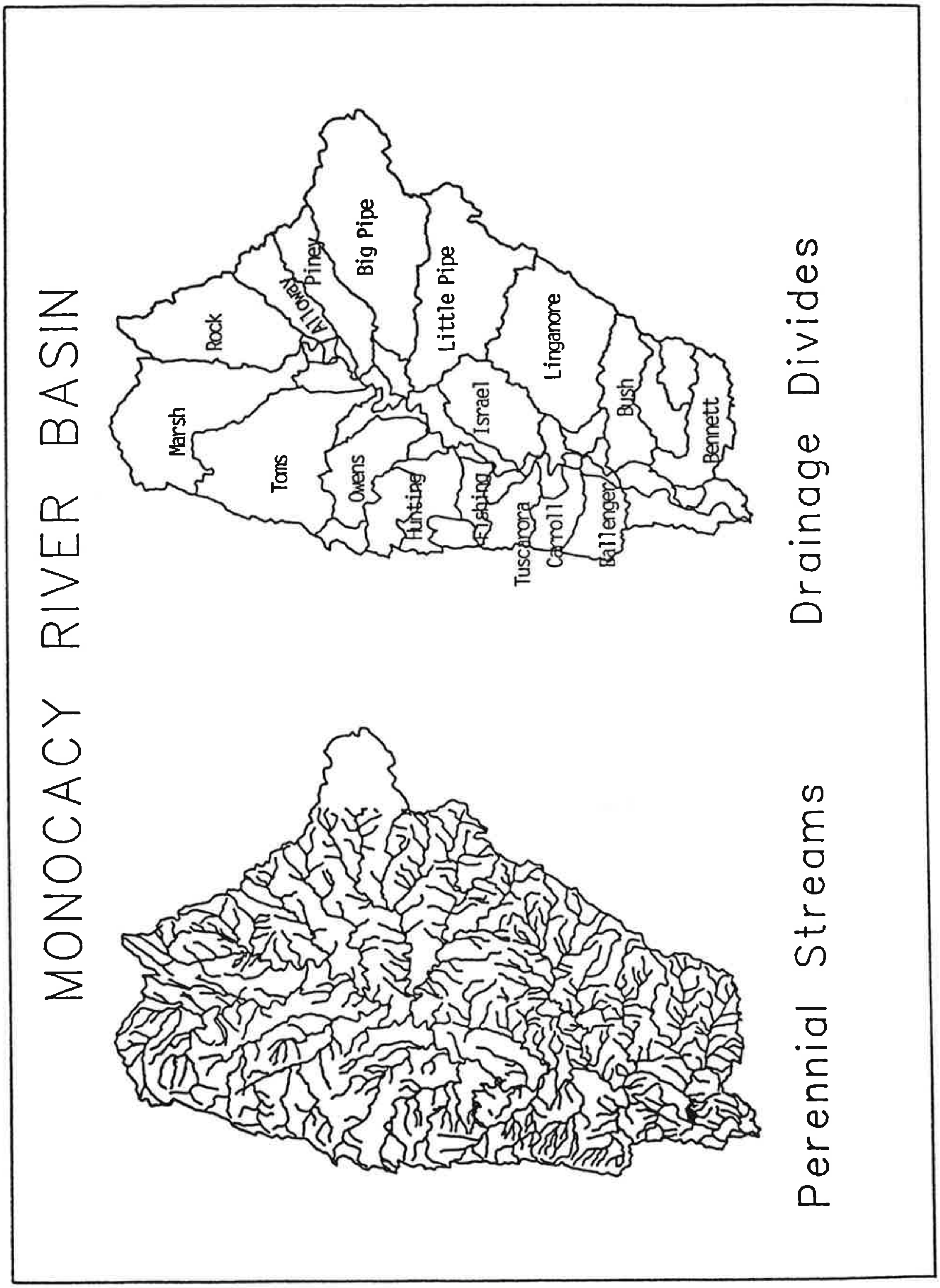


Figure 37. Creeks and Drainage Divides of the Monocacy Basin



SUMMARY

In general, streams in the Monocacy River basin are effluent; that is, ground water flows into the surface streams. Subsurface flows are oriented towards the creeks in the uplands, but discharge directly into the Monocacy River in the lowlands. Ground water flow paths generally correspond to surface drainage patterns.

The Monocacy River Basin is composed of several distinct hydrogeologic areas.

The limestone valley, underlying portions of Israel, Glade, Carroll, Ballenger, and Tuscarora Creeks, presents the most serious ground water quality problems. The highest ground water nitrate and phosphorus concentrations were found in the Ballenger Creek sub-basin. The limestone aquifer is connected directly to the Monocacy River, and, because of the high hydraulic conductivity of the limestone, is expected to deliver large volumes of polluted baseflow to the Monocacy.

The Israel Creek sub-basin has a very shallow water table and exhibited the second highest levels of ground water nitrate contamination. The shallow water table in the Tuscarora Creek sub-basin likewise contributes to the potential for ground water contamination.

Shallow water tables were also encountered in non-carbonate areas, namely in Bennett, Alloway, and Piney Creek sub-basins, indicating an enhanced potential for ground water pollution from surface activities.

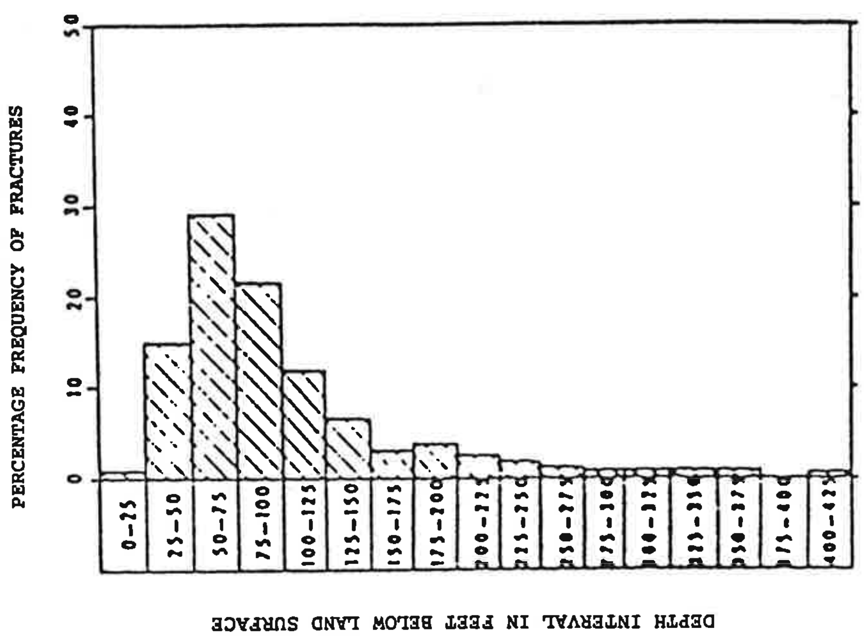
Deeper water tables but high nitrate measurements in recharge areas are found in the Double Pipe Creek sub-basins (Little Pipe Creek and Big Pipe Creek). Also elevated phosphorus levels were detected in discharge areas of these sub-basins.

Linganore Creek showed high ground water nitrate levels in the center of the basin, in the New London area.

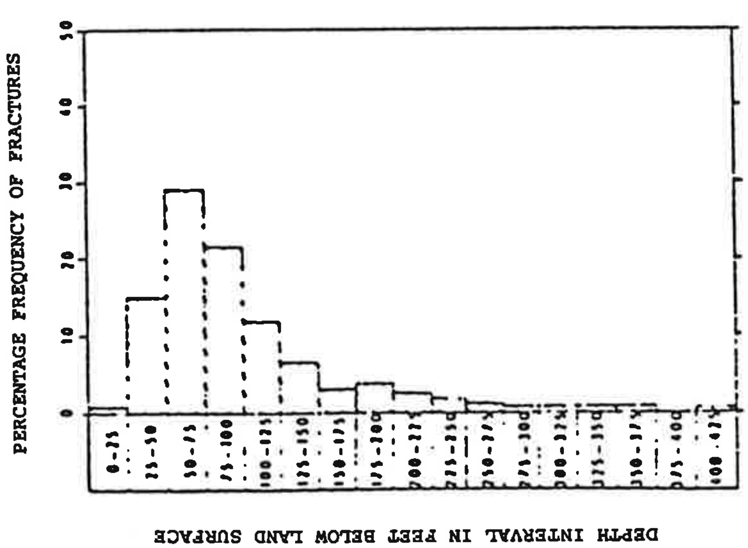
Low to moderate nitrate contamination was observed in Hunting, Fishing, Owens, Toms, Marsh, and Rock Creeks.

Because of the limited number of ground water nutrient concentration measurements, and in some cases, the age of the data, statements about ground water quality are provisional.

APPENDIX *



Percentage frequency of water-yielding fractures in drilled wells in the Westminster and Winfield quadrangles.



Percentage frequency of water-yielding fractures in drilled wells in southern Carroll County.

* SOURCE: Otton and Hilleary, 1979, and Otton, 1980.

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