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FINAL REPORT

# GROUND WATER STUDY AMES-CAMBRIDGE REACH OF THE SKUNK RIVER STORY COUNTY, IOWA

Merwin D. Dougal, Editor
Robert C. Palmquist
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For
**City of Ames, Iowa**

Engineering Research Institute
and the
Iowa State Water Resources Research Institute
Iowa State University
Ames, Iowa

June 1980

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SUMMARY OF FINAL REPORT
AMES - CAMBRIDGE GROUNDWATER STUDY (June 1980)
Prepared By: Story County Planning and Zoning, September 1984

I. CONCLUSIONS AND RECOMMENDATIONS

A. Scope of Study

This study was made "to determine the movement of ground water in this floodplain area and to provide a preliminary evaluation of the potential impact of the new (Ames Water Pollution Control) plant on the community of Cambridge." Two study objectives were to (1) examine potential impacts of a WPC plant at Site 5 on ground water flow patterns and on water quality in the study area, and (2) outline additional observations and studies needed if Site 5 is selected.

B. Conclusions

1. Geology. The Ames Buried Channel Aquifer extends from Ames to Cambridge and lies under Site 5. Cambridge's two city wells are drilled into this aquifer. At Site 5, a layer of alluvium overlies the aquifer, protecting the aquifer from potential surface contamination. (See Fig. 4). At Cambridge the profile is different (See Fig. 5), but there is still a layer of material overlying the aquifer providing "a large degree of protection to the Cambridge wells." (p.4) The aquifer is highly permeable, and water will move readily through it once it reaches the aquifer. However, the surface layer is only 1% to 10% as permeable, limiting the downward movement of water and potential contaminants from the surface to the aquifer.

2. Ground Water. Ground water discharges into the river, but the river will recharge the aquifer during flood stages. Because of the slope of the river combined with the slope of the land, ground water flows at about a 45° angle to the river channel. This "results in a determination that any potential contaminants reaching the aquifer from the Site 5 area would move to the river within one to one and one half miles downstream of the site." (p.6) However, during periods of drought, ground water would travel farther downstream before reaching the river. During droughts there could therefor be a greater adverse effect at the Cambridge well site. However, the report says that during droughts there is less water infiltrating from the surface, and what water there is would be utilized by crops so that there would be little or no excess water

left to move downward. Because of the higher ground water elevation and higher degree of aquifer recharge in the Walnut Creek area, the report recommends that "all land (sludge) disposal areas at Site 5 should remain north of Walnut Creek." (p.7)

3. River Impact. The Skunk River is in "hydrologic connection" with the buried channel aquifer. Earlier, the report stated that the river will recharge the aquifer during flood stages, but here the report stated that because of the low permeability of the layer overlying the aquifer, the influence of flood stages may constitute more of a pressure wave effect and less of a water movement recharge phenomenon. During drought periods, the effluent from Ames may constitute the entire flow of the river. Because of this, it will be desirable to not draw down the aquifer water level too far during drought periods. This could have some impact on Cambridge's ability to pump from city wells during drought periods. If the water level in the aquifer is drawn down too far, water (effluent) from the river may move to the wells. Also, flood protection of facilities at Site 5 is considered a must, including maintaining agricultural levees at sludge disposal areas.

4. Ground Water Quality. The water quality in the aquifer is similar to that at Ames, and will require treatment for use as a supply source. The report states that the aquifer is a valuable source of water supply, but that the use of Site 5 will obviously remove an area from I-35 to Walnut Creek as a potential source of supply. The remainder of the aquifer can still be used as a source for the southern and southeastern areas of the county.

5. Final Site 5 Conclusions. Site 5 is acceptable from a "hydrologic and ground water viewpoint." (p.11) Because of the high moisture retention and low permeability of the surface layer over the aquifer at Site 5, "land disposal of digested sludge can be conducted on such soils." (p.11) Because of the direction of ground water movement, "any potential contaminants, if they reach the aquifer, will move toward the river, reaching it in half the distance to Cambridge." (p.11) At Cambridge, "overlying glacial till protects the Cambridge well field from downward movement of potential surface contaminants. Future evaluation may be necessary if increased well withdrawals reverse the positive, riverward ground water gradient." (p.11) This section concludes by stating that "the nature of ground water flow direction indicated that there will be no adverse quality impacts on the Cambridge well field from proposed operations at Site 5." (p.12)

6. Other Alternative Sites. Use of the present site and Site 4 were discussed, but not in much detail. Both were determined to be acceptable sites.

C. Recommendations.

1. Site Selection. Site 5 was recommended, from a hydrologic and ground water standpoint, to remain as the first priority site.

2. Site 5 Recommendations. Additional recommendations were presented to insure the safe operation of a plant at Site 5. The recommendations dealt with site planning, operations, additional testing, and monitoring programs. (See p.14, 15)

II. STUDY LOCATION AND SITE PHYSICAL CHARACTERISTICS
This section discussed the physical characteristics of the study area and the series of test holes and observation wells which were used to gather the data for the study. Of some note in this section was the discussion of drainage in the Site 5 area, and the recommendation that the existing drainage channel and culvert be left operational if the plant is constructed at Site 5.

III. GEOLOGY
This section discussed the geologic profile of the study area and of Site 5. Again, it was stated that the buried channel aquifer extends from Site 5 to south beyond Cambridge, and that the aquifer is covered by 12 to 53 feet of alluvium which serves to protect the aquifer from surface water contamination. The ground water geology of the area was discussed in two aspects: (1) the location and extent of the ground water recharge area, and (2) the direction of ground water flow. Ground water recharge is said to occur in 3 ways. By vertical infiltration of surface water, by horizontal movement of ground water from upland areas, and by bank seepage from the river during flood stages. At Site 5, it was concluded that the greatest influence for recharge is the floodplain (vertical infiltration) and bank seepage during flood stages.

IV. GROUND WATER MOVEMENT

A. Regional Ground Water Regimen
This section was basically a review of information presented earlier regarding ground water recharge and movement. Again, recharge occurs from 3 sources: (1) vertical infiltration, (2) horizontal inflow of ground water from upland areas, and (3) bank seepage from the Skunk River. It was repeated that the magnitude of influence on recharge from upland ground water is less than what may be expected from the size of the drainage area.

B. Ground Water Flow Patterns.

Ground water flow patterns over both the long-term and the short-term were discussed. (Long-term includes periodic drought effects.) Long-term ground water flow patterns can be inferred from the surface topography of the area. "The inferred (long-term) ground water flow lines in the study area indicate that flow in general is eastward from the uplands and then southeasterly diagonally down valley toward the Skunk River. With this pattern ground water passing under Site 5 would discharge into the Skunk River within a mile downstream." (p.38) The report stated that short-term observations, taken from actual measurements, confirm the conclusions drawn from the topographic analysis regarding long-term patterns. The short-term analysis reinforced the conclusion that ground water flowing under Site 5 does not pass near the portion of the aquifer from which Cambridge draws its water. (See Fig. 8) This section states that, based on this information, "the potential for contamination of the Cambridge ground water supplies by Site 5 appears to be low." (p.40) It was recommended here that, because of ground water flow patterns, sludge disposal on Site 5 should be in the areas nearest the river to allow for rapid discharge and dilution of contaminated ground water.

Results from previous studies in the area of the existing Ames solid waste disposal site were presented which supported the conclusions regarding short- and long-term ground water flow patterns. However, a note of caution was thrown in. These studies indicated that ground water contamination from the existing disposal site was characteristic of a long-term flow pattern, that is, contamination was found to be farther downstream and more widely dispersed than short-term flow patterns might indicate. The report stated that, during drought periods, ground water flowing beneath Site 5 may continue down-valley and possibly pass into the withdrawal area of the Cambridge well field. (Note: This conclusion should be referenced with previous information regarding well draw down in the Cambridge area during drought periods, and the fact that during drought periods the river flow may consist entirely of effluent. Excessive draw down by Cambridge may result in the river flow (effluent) moving to the wells. It appears from these two pieces of information, then, that extended drought periods may have an adverse effect on the Cambridge water supply.) Excerpting from the report (p.43):

> The results of the ground water study can thus be summarized. The short-term data (normal and low flow periods) indicate that contamination of the Cambridge water supply by activities at Site 5 is unlikely. The longer-term data suggest,

during drought periods, that ground water flowing beneath Site 5 may continue down-valley and possibly pass into the withdrawal area of the Cambridge well field. However, little percolation through the flood plain soil profile will occur during these drought events.

In summary, the analysis of the ground water flow at Site 5 indicates that potential for contamination is small, because of the dilution effects and the good soil moisture retention expected from the soil. Any contamination which might occur can be minimized by placing sludge on the flood plain areas nearest the river and minimizing the amounts placed along the bluff areas.

C. Summary of Aquifer - River Relationships.

Again, both storm surface runoff and ground water flows discharge into the river. During flood stages, chemicals and other dissolved materials can penetrate to the aquifer, but are highly diluted.

D. Ground Water Quality.

Routine ground water quality tests were performed on samples taken from each of the 7 observation wells. The water quality was found to be similar to water samples from the Ames well field. Heavy metals were not tested, but the report states that "if Site 5 is selected for use, then these tests should be made." (p.48)

## V. FLOOD IMPACT

Because Site 5 is located in a flood plain area, an initial appraisal of the flood risk at the site was made. Information gathered from the June 1975 flood of record was used to base inferences on the expected 2-, 5-, 10-, 25-, 50-, and 100-year flood interval levels. (See Table 3.) The report states that these are preliminary results and should be verified by additional hydraulic studies if Site 5 is selected.

Several recommendations were made regarding flood protection for the facility and sludge disposal areas. They include placement of the high-risk facilities in the bluff area west of the old channel and north of the east-west county road, protection of the sludge disposal areas by levees, and interior drainage considerations.

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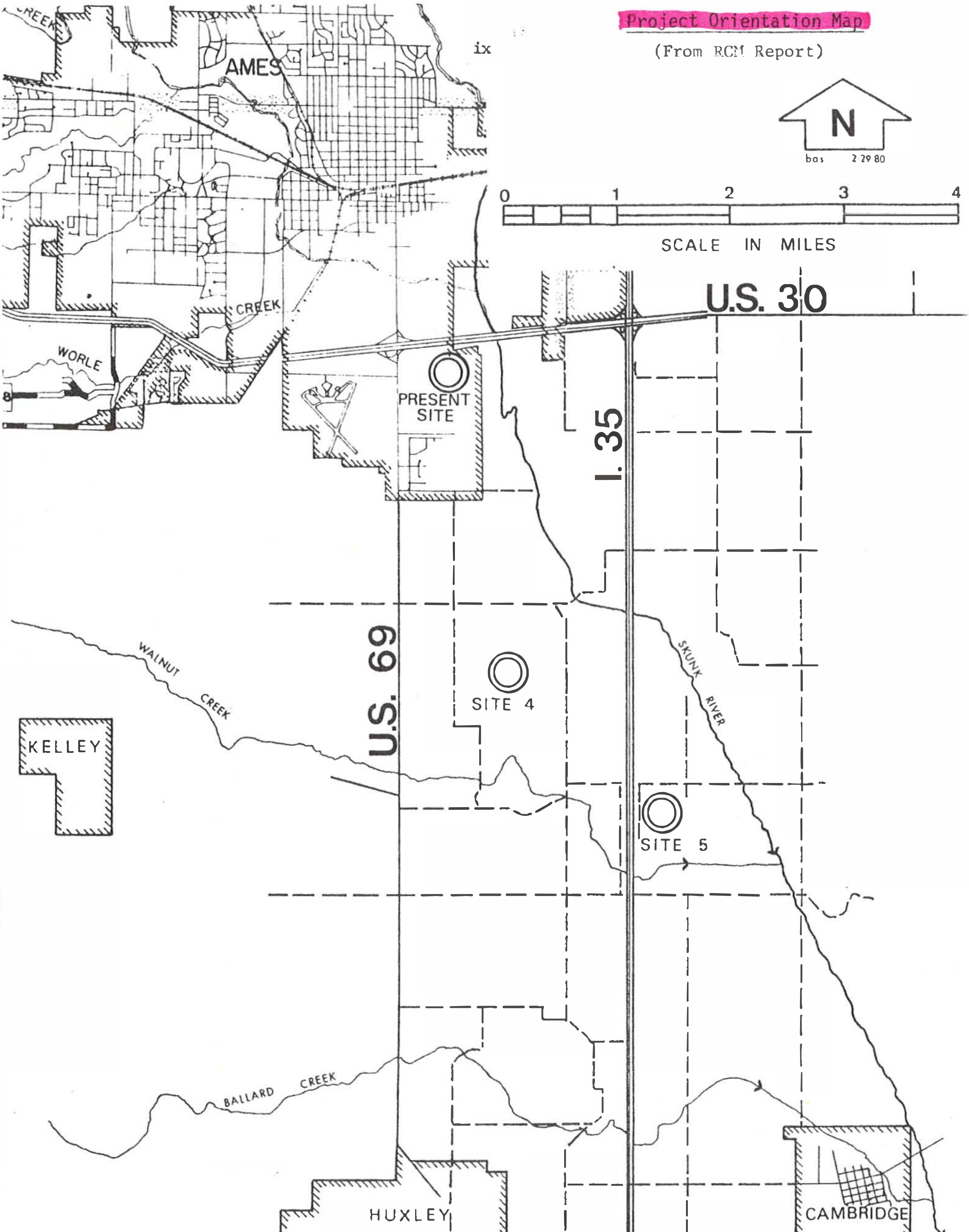
Project Orientation Map

(From RCM Report)



# 1. CONCLUSIONS AND RECOMMENDATIONS

## 1.1. Scope of Study

A brief study has been made of the downstream continuation of the Ames Buried Channel Aquifer from Ames to Cambridge. The flood plain area studied in greatest detail lies west of the Skunk River, extending from Interstate Route I-35 to Iowa Highway 210, south of Cambridge. This area includes Site 5, one of the alternatives being considered as a new water pollution control plant location by the City of Ames. The site is located midway between the corporate limits of the two communities.

The proposed water pollution control plant would discharge effluent into the Skunk River east of the plant site. In addition, land disposal of digested sludge is proposed in an agricultural area surrounding the plant site. This study was made to determine the movement of ground water in this flood plain area and to provide a preliminary evaluation of the potential impact of the new plant on the community of Cambridge, which has ground water wells drilled into the buried channel aquifer.

Study objectives included the following:

1. Drill test borings and install observation wells to determine aquifer characteristics and ground water levels in the study area. Further, relate these to stream levels in the Skunk River and in Ballard Creek at Cambridge.
2. Determine the general magnitude and direction of the gradient of ground water in the valley and under the higher terrace on which Cambridge is located. Illustrate the general pattern

of ground water movement in both the valley and terrace areas and interpret the relationship of the ground water levels to the Skunk River surface water levels.

3. Provide a report which indicates the potential impact of a water pollution control plant located at Site 5 on ground water flow patterns and on water quality in the study area.

4. Outline the additional observations and studies needed if the site is selected for use as the Ames Wastewater Treatment Plant.

## 1.2. Conclusions

### 1.2.1. Geology

The Ames Buried Channel Aquifer is continuous in the reach from Ames to Cambridge, as indicated from the seven test boreholes drilled during the study and from other well data sources. The deepest part of the eroded bedrock valley continues from the Squaw Creek valley alignment at Ames on downstream, following the Skunk River valley alignment to Cambridge. Old glacial till deposits lie over the bedrock with the coarse sands and gravels (and cobbles) of the buried channel aquifer lying above. Younger alluvial deposits of sands, silts, and clay cover the aquifer providing agricultural soils having exceptional yield potentials. Specific conclusions are:

1. The Ames Buried Channel Aquifer extends from Ames to Cambridge as a consistent and fairly uniform bed of coarse sand and gravel. It lies under Site 5 and the flood plain areas designated as land

disposal sites for digested sludge and extends under the glacial deposits on which Cambridge is located (above the flood plain). The two city wells at Cambridge were drilled vertically into this aquifer from the upland location.

2. Stratigraphic data obtained at the two boreholes at Site 5, Observation Wells 1 and 2 (OW-1 and OW-2), illustrate the general nature of the alluvial deposits in the study area. At the surface, the agricultural soils have a good silty clay loam and sandy clay loam texture. Below the surface there are 12 to 24 feet of clay, silt, clayey sand, and fine sand which cap the underlying aquifer. Beneath this fine-grained alluvium are 34 to 65 feet of medium to coarse sand and gravel, which constitute the aquifer formation.

3. At Site 5 there is a minimum of 12 to 15 feet of clay, silt, and clayey sand at the surface which protects the aquifer against potential surface contamination, whether it be from agricultural or urban sources. This surface formation extends on downstream to Cambridge where Ballard Creek flows at the foot of the upland area on which the community is situated.

4. At Cambridge the stratigraphic profile of the upland terrace-like deposits shows a surficial layer composed of interbedded till, clay, sand, and sand and gravel from 27 to 53 feet thick. A shallow veneer of fine brown sand lies just below the surface soils. Below the surficial layer are 43 to 53 feet of sand, sand and gravel, and coarse gravel. Till lies below this. These underlying coarse sands

and gravels are part of the Ames Buried Channel Aquifer. Again, the overlying surficial deposits provide a large degree of protection to the Cambridge wells from potential surface contaminants moving vertically downward.

5. The permeability of the aquifer is great, illustrating the ability to yield substantial quantities of water from wells drilled into the lower portion of the aquifer. Water will move readily once it reaches the aquifer, either from upland recharge, flood plain infiltration, river bank seepage during floods, or river bed seepage if local well drawdown is excessive. Coefficients of permeability, estimated from grain size distribution analysis of borehole samples in the study reach, range from 500 to 3000 gallons per day per square foot per unit gradient (gpd/ft), or 67 to 400 feet per day per unit gradient (apparent permeability). This would correspond to a pore velocity in the formation of 0.2 to 0.3 feet per day to 1.2 to 1.6 feet per day (porosity of 0.15 to 0.20), for the 3.2 feet per mile gradient of the downstream river and flood plain. In contrast, it is estimated that the surface formations (top 12 to 20 feet) have a permeability of only one percent to 10 percent of the aquifer permeability. This limits the rate of downward movement of water (and potential contaminants) from the surface to the interface with the aquifer.

1.2.2. Ground water

Observations were made at all seven observation wells (OW-1 to OW-7) and at three stream locations for the February to May period.

Ground water flow maps and valley cross sections were drawn to illustrate the magnitude and direction of ground water flow. Observations were made also of water levels in the Skunk River.

Specific conclusions are as follows:

1. The ground water elevation data show that the piezometric surface is above river level during normal and low flow periods. The water level in wells near the bluff (1/2 to one mile perpendicular from the river) are from two to four feet above the water levels in the river. The relatively low values reflect the high permeability of the aquifer and its ability to transport readily the seepage arriving at its boundaries.
2. The Skunk River is the discharge sink for ground water flow in the basin from uplands to the flood plain and thence to the river. Present and previous studies show that the river recharges the aquifer and causes the piezometric surface to rise during the passage of flood flows. Following a flood crest, the piezometric surface gradually declines, as does the river stage.
3. Ground water flow during normal or low flow periods responds to two gradients. The downstream valley and stream gradient is 3.2 feet per mile through the study reach. The transverse gradient, from bluff to the river, is from 2 to 4 feet per mile. Ground water flows in the direction of the resultant of these two scalar gradients, which is about 45° to the channel

alignment, in the downstream direction. This results in a determination that any potential contaminants reaching the aquifer from the Site 5 area would move to the river within one to one and one half miles downstream of the site.

4. During extremely low flow drought periods, the transverse gradient decreases as the piezometric surface decreases at the bluff line and across the valley. This would yield a greater downstream direction to the resultant flow lines. Thus, during droughts there could be a greater adverse effect at the Cambridge well site. However, during such drought periods there is much less infiltration from the surface reaching the ground water aquifer. Soil moisture would be utilized to a more complete degree by agricultural crops with little or no excess water left to move downward.

5. Flow net analysis shows that under normal climatic and streamflow conditions any water infiltrating downward at Site 5 (and including its land disposal areas) would move diagonally to the river along the top portion of the 30 to 40 feet thickness of coarse sand and gravel or above this in the fine sands. The lower portions would carry ground water reaching the aquifer from upland areas, from flood plain areas near the bluff line, or from other buried channel areas lying to the west. During drought periods, there would be a greater hydraulic tendency for deeper penetration and greater downstream movement, but less water will be moving downward to the aquifer.

In all cases, dilution will also occur from diffusion and dispersion processes. This lessens the concentration at any one point, compared to no diffusion or dispersion, but can cause some outward movement of low concentrations.

6. Walnut Creek flows eastward from the bluff line to the river, about 3/4 mile downstream from Site 5. There is topographic evidence of additional alluvial deposits at its entrance to the valley, which gives the area higher ground elevations than would be expected without its presence. The slightly higher ground water levels observed at OW-3 are believed due at least partially to this phenomenon. This causes the flow lines to move more directly to the river. The semi-perched nature of the stream could cause additional recharge to the underlying aquifer and also be partially responsible for the slightly elevated ground water levels at OW-3. This does indicate that all land disposal areas at Site 5 should remain north of Walnut Creek.

7. At Cambridge the topography slopes eastward, and somewhat northeastward (on the south side of the railroad). In addition, Ballard Creek flows in a drainage ditch across the flood plain from the west bluff to the upland terrace and around the perimeter to its confluence with the Skunk River east of Cambridge. This stream is a perched stream and does not appear to offer more than a minor amount of recharge to the aquifer. The ground water gradient is largely eastward because of the topography and its effect on ground water recharge. Again, this

assists in protecting the Cambridge well field from potential contamination from the north, from whatever source---agricultural chemicals, urban effluent from Huxley or Ames, or sludge disposal at Site 5.

8. The upland area west of Site 5 and east of I-35 might serve as an experimental land disposal site, since it is in deep till. Because the land topography slopes and the surface runoff flows to the south on the east side of I-35 and then to the drainage way flowing eastward, no impact on the land surface or on the ground water table west of I-35 is foreseen.

1.2.3. River Impact

The Skunk River is in hydrologic connection with the buried channel aquifer. During flood periods the river will cause an increase in ground water levels in the aquifer. However, the low permeability of the overlaying stratum implies that the aquifer may be semiconfined and does not act entirely as an unconfined ground water table aquifer. Therefore, the influence of flood stages may constitute more of a pressure wave effect and less of a water movement recharge phenomenon.

Specific conclusions are as follows:

1. Effluent from Ames will, as in the past, continue to be discharged to the river. During low flow drought periods, it may constitute the entire flow of the river. In addition, Huxley discharges its effluent into Ballard Creek, which flows around the north and east perimeter of Cambridge. This indicates

that it is desirable to keep a positive ground water gradient to the river (eastward) in the aquifer underlying the community of Cambridge.

2. During low flow periods the water levels in the Cambridge wells may decline to a level two feet or less above the stream level. Therefore, the safe drawdown potential available during well withdrawal periods is not great. Intermittent pumping to supply the community of 650 to 700 persons would not cause any drawdown problems. However, continuous pumping of both wells over an extended pumping period (a week or more) could cause a reverse gradient from the river toward the wells. This would cause a movement of water from the stream to the wells, but withdrawals would be further diluted by the upland and the downstream ground water flows. There is no immediate concern now, but continued growth both of Ames and Cambridge could lead to a need for reevaluation in the future.

3. Flood protection must be provided at Site 5. This could be accomplished in a cost effective manner by (a) elevating the immediate plant site to the 100-year flood elevation (estimated to be Elevation 866 to 867) plus freeboard, (b) constructing administration and laboratory units in the bluff above the flood plain level, and (c) maintaining the agricultural levees at a 5- to 10-year frequency flood elevation (estimated to be at Elevation 862 to 864). In addition, tie back levees

would be required along the north bank of the Walnut Creek drainage ditch and northward to the plant site on the proposed access road to the proposed plant site.

### 1.2.4. Ground Water Quality

The water samples taken at each observation well (OW-1 to OW-7) were analyzed and compared with the raw water analyses made at Ames from its municipal well field (the same buried channel aquifer). The usual physical and chemical analyses were made. Detailed analyses for heavy metals were not made, because of the cost and time involved. However, background values should reflect those taken previously at Ames by the Iowa Department of Environmental Quality (DEQ) under federal Environmental Protection Agency (EPA) requirements.

Specific conclusions are:

1. The water quality in the aquifer, for the selected parameters, is similar to that measured at Ames. Iron removal and softening are required to produce a water supply acceptable to modern day consumers.
2. The Ames Buried Channel Aquifer, from Ames to Cambridge (and on to Iowa Highway 210 and the Story-Polk County line) is a valuable source of water supply. The use of Site 5 undoubtedly would preclude the immediate area of I-35 to Walnut Creek from being considered as a source of supply. However, the east side of the valley and both east and west flood plain areas south of Cambridge would remain available as sources of supply. The southern and southeastern areas of Story County could well be served from this water supply source.

## 1.2.5. Final Site 5 Conclusions

Concluding statements are as follows:

1. Site 5 is an acceptable site for a water pollution control plant, as its location is reviewed from a hydrologic and ground water viewpoint.

2. The surficial soil profile at Site 5 consists of silts, clays, and clayey sands to a depth of 12 to 15 feet. This implies slow infiltration and good retention of soil moisture. It is estimated that movement of excess water downward to the underlying Ames Buried Channel Aquifer is slow. Land disposal of digested sludge can be conducted on such soils.

3. The ground water movement is diagonally toward the river during normal and low flow periods. Any potential contaminants, if they reach the aquifer, will move toward the river, reaching it in half the distance to Cambridge. During drought periods the flow of ground water moves more directly down valley, but greatly reduced quantities of downward seepage from the flood plain or lateral seepage from the upland would occur during such periods.

4. The ground water levels at Cambridge are greater than the river level during normal or low flow periods. The flow movement at the Cambridge plateau or terrace is toward the river, deflecting eastward any down valley ground water movement. [illegible]lying glacial till protects the Cambridge well field from downward movement of potential surface contaminants. Future evaluation may be needed if increased well withdrawals reverse the positive, riverward ground water gradient.

5. Water quality in the buried channel aquifer is characteristic of surficial aquifers with considerable iron and hardness components. The nature of ground water flow direction indicated that there will be no adverse quality impacts on the Cambridge well field from proposed operations at Site 5. There probably is a greater impact potentially from applications of agricultural chemicals on the flood plain areas adjacent to the community.

1.2.6. Other Alternative Sites

Both the existing plant site and Site 4 were included in the city's final evaluation studies. A brief field inspection was made of these sites concerning hydrologic and ground water impact.

1. The use of the existing plant site would parallel the use of Site 5. Flood protection would be required for low-lying facilities. There is little available upland area remaining for new construction. Effluent would be discharged to the east, into the Skunk River.
2. Land disposal of digested sludge at the present site could take place at one of two locations, or both could be utilized. One potential area is the flood plain area located west of the Skunk River, from U.S. 30 to I-35. The second potential area is located east of the Skunk River; this area is the agricultural land east and west of I-35 north of the I-35 Skunk River bridge. This second area is a greater haul distance from the present plant site, which would favor use of the west area. However, the west area is located adjacent to residential areas and many rural residential homes.

3. Site 4 is an upland area (S½ Sec 25; Sec 36). The north part of the area drains to the north. The southern 2/3 of the area, which is considered as the facility site, drains from the bowl-like depressional area southward to Walnut Creek. The ground water table aquifer in this upland area, consisting of glacial till deposits, would cause ground water to move southward. The ground water table would parallel the ground surface. Because of the underlying till, no pollution potential exists to the buried channel aquifer. The ground water flow lines are contained in the bowl-like depression, so no adverse effect upon the shallow or deep wells of the surrounding rural residential houses is foreseen.

## 1.3. Recommendations

### 1.3.1. Site selection

1. All three sites, as evaluated, are suitable sites from the standpoint of potential impact on ground water and land suitability for disposal of digested sludge. Site 5 remains the most isolated site, and land disposal would affect the least number of persons and housing units. The land disposal of digested sludge would influence the fewest flood plain wells, providing the three farmsteads at Site 5 are acquired if this site is selected. It is recommended, from a hydrologic and ground water standpoint, that Site 5 remain as first priority. Acquisition of Site 5 should include all three rural

residential or farm residences at the site to eliminate any environmental and water-related impacts adjacent to the plant and land disposal areas.

2. One more costly alternative would be to continue the outfall five miles southward to a point about two miles south of Cambridge. However, consideration of this alternative site would necessarily include a regional scope to water quality control. A regional plant could serve Ames, Kelley, Huxley, Cambridge, and perhaps Nevada also. Consultant reports show this is not cost effective at this time, and the EPA and the Iowa DEQ have not requested further studies. This alternative should receive additional attention if Site 5 is not selected.

### 1.3.2. Site 5 Recommendations

If Site 5 is selected, the following additional recommendations should be considered:

1. Construct all facilities north of the east-west county road located at Site 5. Provide flood protection at the site as outlined in this report.
2. If additional land disposal areas can be made available through cooperative application contracts, then it is recommended that the allowable amounts of digested sludge be spread on flood plain lands nearest the river and lower amounts on lands near the bluff.
3. Make periodic observations of well levels and water quality parameters.

4. Conduct additional percolation tests of the surface soils.
5. Consider adding an observation well between OW-3 and the Skunk River. This is needed to confirm the initial conclusions regarding the effect of Walnut Creek on ground water levels at OW-3.
6. Begin to evaluate the water quality in the observation wells (OW-1 to OW-7) for heavy metals and related constituents (found in the Ames sludge) which are potential contaminants.
7. Plan an effective monitoring program to measure the environmental impact of plant operation and land disposal of digested sludge. Quality sampling of river water will be as important as other ground water observations.
8. Maintain a communications linkage with the City of Cambridge, its City Council, water plant personnel, and other public works administrators to discuss plant design, construction, operation, and maintenance. Annual review meetings for a 5- to 10-year period or longer are recommended.

# 2. STUDY LOCATION AND SITE PHYSICAL CHARACTERISTICS

## 2.1. Project Location and Observation Network

The study area extends from the I-35 bridge to the Iowa Highway 210 crossing of the Skunk River downstream of Cambridge. Geological data were obtained from test borings of the Iowa Department of Transportation (DOT) taken along the I-35 alignment. In addition, seven test boreholes were drilled by the Layne-Western Company for the project, with observation wells (OW) being installed in each. Split-spoon samples were taken at each test site, and a geological log established for each. The location of the boreholes and observation wells are shown in Fig. 1. The observation wells were test pumped, and samples were collected for hydrogeological and water quality analysis. Two test holes were drilled along the east-west county road at Site 5, while a third was drilled one mile south. The fourth was drilled just north of Cambridge, north of Ballard Creek. The remaining three holes were drilled in Cambridge, one near the church northwest of Main Street, a second at the southwest corner of Cambridge west of the highway underpass, and a third east of town in the ball park, on the east side of Ballard Creek.

Particle size analyses were made for samples obtained at OW-1 and OW-2 at Site 5. These assisted in estimating the aquifer permeability. Water level observations were made periodically during the February to May study period. All observation wells have responded to increases in river stages of the Skunk River during the late March snow melt period. Observation well and stream stage data were obtained and plotted. A preliminary analysis of ground water movement was made also, and flow nets were sketched.

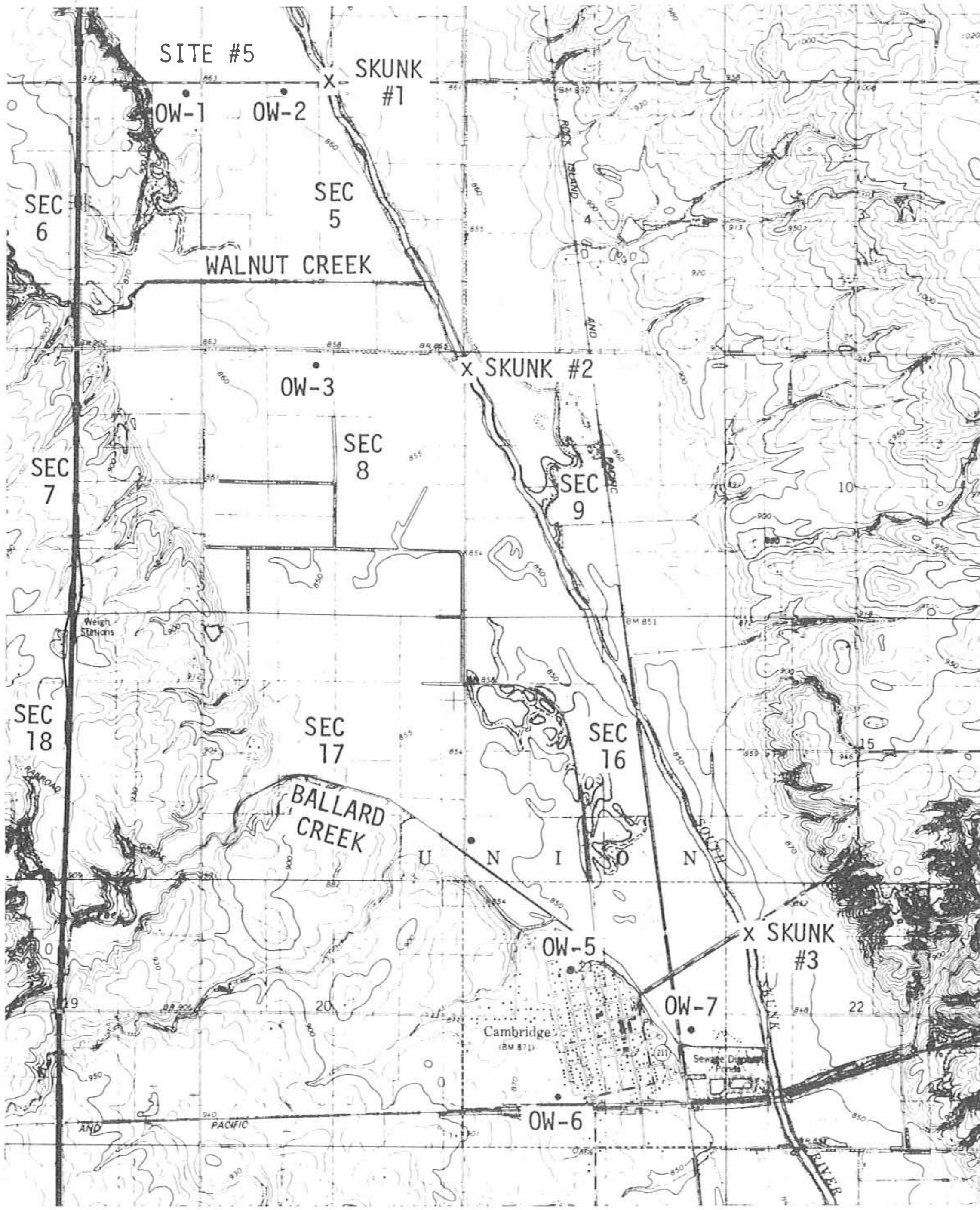



Fig. 1. Location map showing Site #5, Cambridge, and the boreholes and Skunk River sample sites.

Data from previously established observation wells along Iowa Highway 210 were used also. (The earlier study data are included in this report). This east-west series was drilled and observation wells were established for the Ames Reservoir Environmental Study in the early 1970's.

All seven new observation wells and the stream gaging sites were surveyed by the research team. The stream slope is about 3.2 feet per mile. Basic survey information is included in the appendices, along with borehole data, stratigraphic analysis, and laboratory results of the water quality sampling program.

## 2.2. Stream and Valley Gradients

Field instrument surveys were made from Site 5 to Cambridge to establish observation well elevations and bridge elevations at three locations. Observations were then made of river levels in the Skunk River to determine the slope of the water surface (river gradient) in the study reach. The data are shown in Figure 2. A review was made also of the river gradients presented in a U.S. Geological Survey 1975 flood report (Lara and Heinitz, 1976). These results are tabulated in Table 1. The gradient is decreasing in the downstream direction, as normally experienced. Through the study reach the gradient is 3.15 feet per mile, a mild stream slope. This is less than one-half the gradient upstream of Ames and reflects also the change in valley width which occurs as the Skunk River enters the much larger, downstream valley at the confluence of Squaw Creek and the Skunk River.

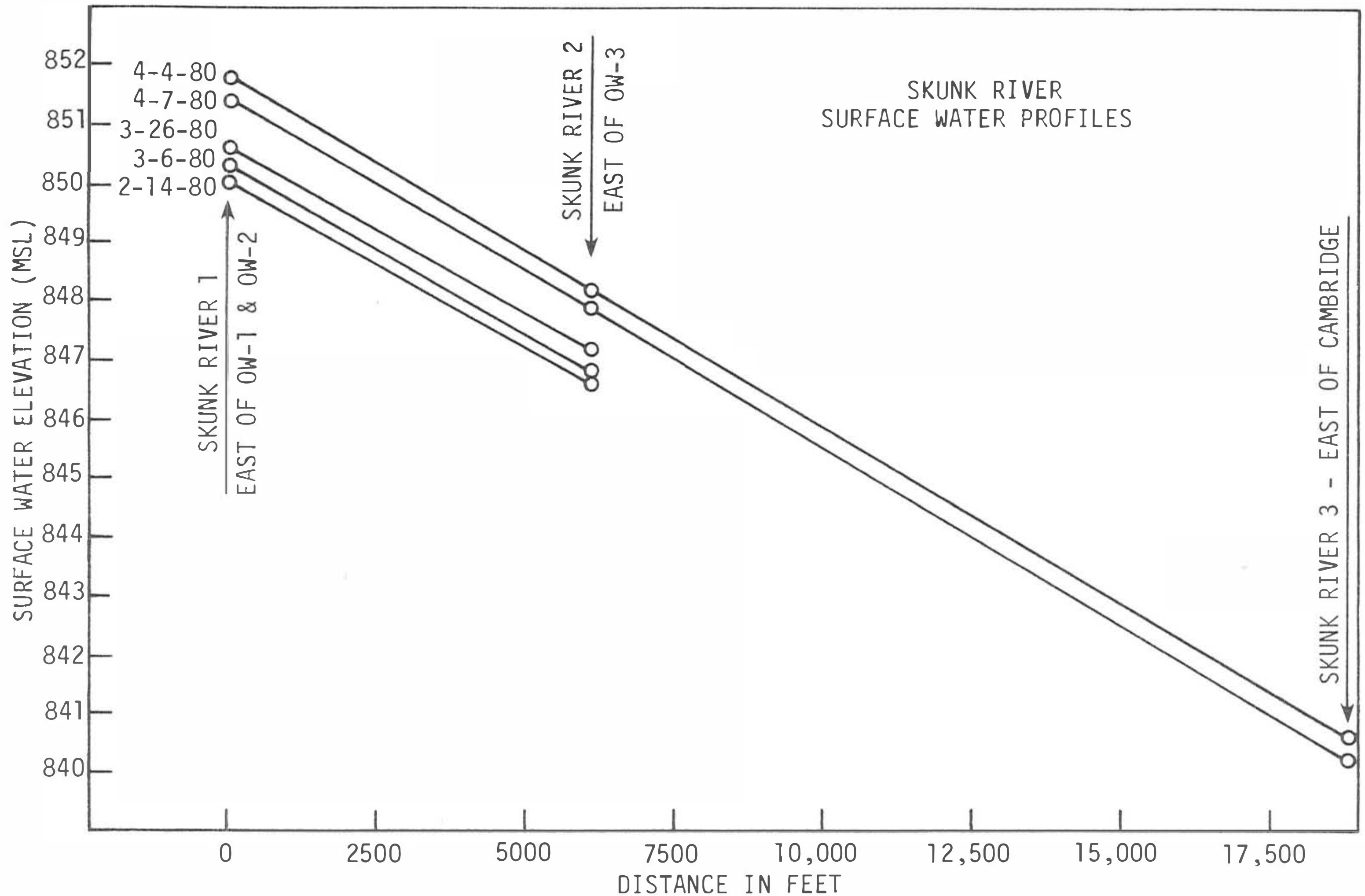



Fig. 2. Skunk River surface water profiles.

Table 1. River gradient of the Skunk River at Ames, Iowa.

| Location | River Mileage[a] | River Gradient, feet per mile |
|---|---|---|
| Skunk River upstream of Ames | - | 7 to 8 |
| Skunk River at Ames NE Gage to So. 16th St. | 223-228 | 4.9 to 5.0 |
| Skunk River at Ames So. 16th St. to I-35 | 219-223 | 4.0 to 4.1 |
| Skunk River in study reach, I-35 to Cambridge | 214-219 | 3.1 to 3.2 |

[a]Miles above confluence with Mississippi River

The flood plain slopes at the same rate in the study reach. The distance between the 870 and 860 feet flood plain contours is about three miles. The 850 foot contour crosses the valley just upstream of Cambridge.

The land surface at Site 5 undulates somewhat, but the higher elevations are at Elevation 863±. There is a gentle slope toward the river, with the land sloping from 862± feet at OW-1 to 858± feet at OW-2.

## 2.3. Land Use and Drainage

The flood plain of the Skunk River is farmed intensively. The river flows in a straightened channel, which was constructed in the early 1900's to replace the former meandering channel and to drain the swampy flood plain. Timbered areas along the old meandered channel in the study area have been cleared to improve farming operations and gain more farmland acreage. The main channel has deepened and widened through the years, so that the river overflows rather infrequently. The channel is beginning to meander once again, posing problems at several locations. The largest flood of record occurred in 1975 (slightly greater than a hundred-year frequency flood) and caused widespread flooding of the valley.

Levees have been constructed along the river in many places. Site 5 lies landward of an agricultural levee system. The area is protected further by an upstream, right bank levee constructed as part of the

Interstate I-35 project. This levee was constructed from the I-35 bridge northwestward to the bluff and protects I-35 from overflow during major flood events. A hundred-year frequency flood will not overtop the levee protecting I-35. The remaining agricultural levees are not so high or comprehensive and will overtop if a 5- or 10-year frequency flood occurs.

Interior drainage behind this levee system at Site 5 must be considered in site evaluation. All of the runoff from the tributary upland areas and surface runoff from the flood plain areas must be accounted for in planning use of the site. The interior drainage area begins at the northwest point where the Iowa DOT levee meets the west valley bluff near the county road bridge upstream of the I-35 bridge. A drainage channel and culvert deliver the drainage flow to the east side of I-35 at the bluff line. Interior drainage waters then flow in the old Skunk River channel to Site 5 and then southward to the Walnut Creek outlet ditch. During high flood stages on the Skunk River, flood water can back up Walnut Creek and northward in the old channel. This drainageway must be left operational at Site 5 if a treatment plant is constructed at the site.

# 3. GEOLOGY

## 3.1. Geologic Setting

Site 5 is located on the west margin of the flood plain of the Skunk River in Section 5, Township 82 North, Range 43 West. In this section the Skunk River valley overlies a larger buried bedrock valley (Fig. 3) filled with sands and gravels of Pleistocene age (Twenter and Coble, 1965; Kent, 1969; Palmquist and Bible, 1974; Palmquist, Bible, and Sendlein, 1974). The buried valley has an estimated width of five miles and a depth of 100 feet. In contrast, the modern valley of the Skunk River is two miles wide and 100 feet deep. The age of the buried valley is unknown, but it may be pre-Kansas (Palmquist, Bible, and Sendlein, 1974). The last glacial event was the advance of the Cary age glacier, some 14,000 years ago (Ruhe, 1969), with its subsequent melting by 13,500 years ago (Walker, 1966). Deglaciation was probably by ice stagnation as indicated by numerous minor moraines on the uplands (Palmquist and Conner, 1978; Foster, 1969; Bohlken, 1980). During each deglaciation the Skunk River valley acted as a meltwater channel and received another increment of sand and gravel (Sendlein and Dougal, 1968; Palmquist, Bible, and Sendlein, 1974). These deposits formed the sand, gravel, and till body known locally as the Ames Aquifer (Backsen, 1963; Schoell, 1967; Sendlein and Dougal, 1968) or more generally as the Ames Buried Channel Aquifer (Twenter and Coble, 1965). Subsequent to deglaciation, the Skunk River deposited additional sediments and widened its meltwater valley.

The buried Skunk River valley is eroded into rocks of Pennsylvanian age (Twenter and Coble, 1965; Kent, 1969). In the Ames-Cambridge area

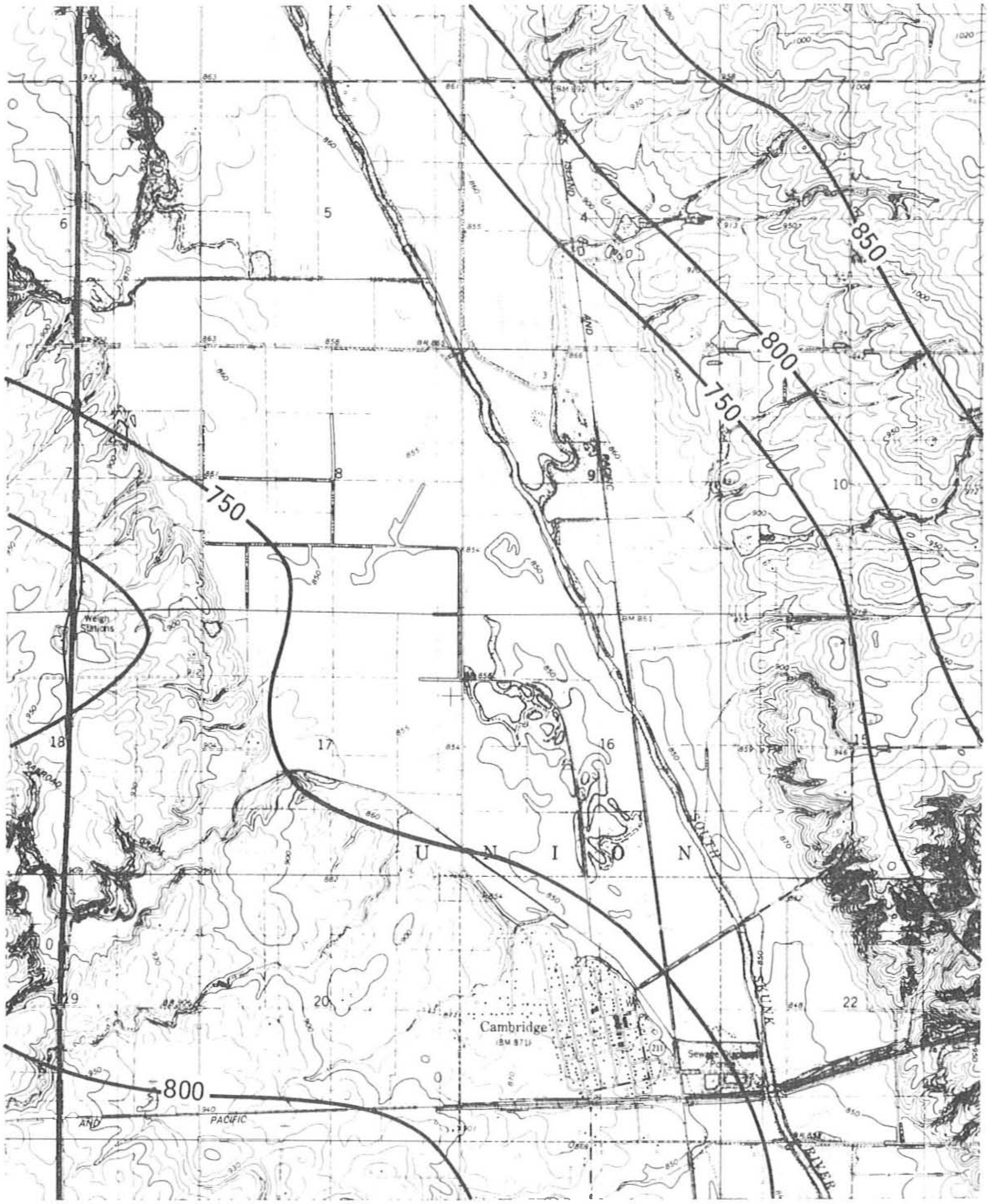



Fig. 3. The Skunk River buried valley with the floodplain of the Skunk River superimposed (from Twenter and Coble, 1965).

these strata belong to the Lower Cherokee Group and are composed of sandstones and shales (Zimmerman, 1952). These rock units have a low permeability and form a barrier preventing the upper bedrock aquifer (Twenter and Coble, 1965) from discharging ground water into the sands and gravels of the Ames Aquifer.

Previous studies indicate that the Skunk River is a major ground water discharge zone. Kent (1969) demonstrated that the river is a discharge zone on a regional basis. On a more local level, Palmquist and Sendlein (1975) demonstrated it for Ames.

## 3.2. Alluvial Stratigraphy

The general stratigraphy of the regolith in the buried valley is sands and gravels, capped by a silty alluvium, which becomes more gravelly with depth (Sendlein and Dougal, 1968; Schoell, 1967). The regolithic stratigraphy between Site 5 and the city of Cambridge was investigated by a series of boreholes (Fig. 1) which are described in detail in the Appendices.

The two boreholes at Site 5 (OW-1 and OW-2) indicate that 12 to 24 feet of clay, silt, clayey sand, and fine sand cap the aquifer (Fig. 4.). This fine-grained layer probably represents the alluvium deposited by the modern Skunk River. Beneath the fine-grained alluvium are 34 to 65 feet of sand and sand with gravel which constitute the Buried Channel Aquifer. Beneath the sands are either till or shale. The boreholes confirm that Site 5 overlies the Buried Channel Aquifer, but that it is protected from potential surface contaminants by a minimum of 12 feet of silt and clay.

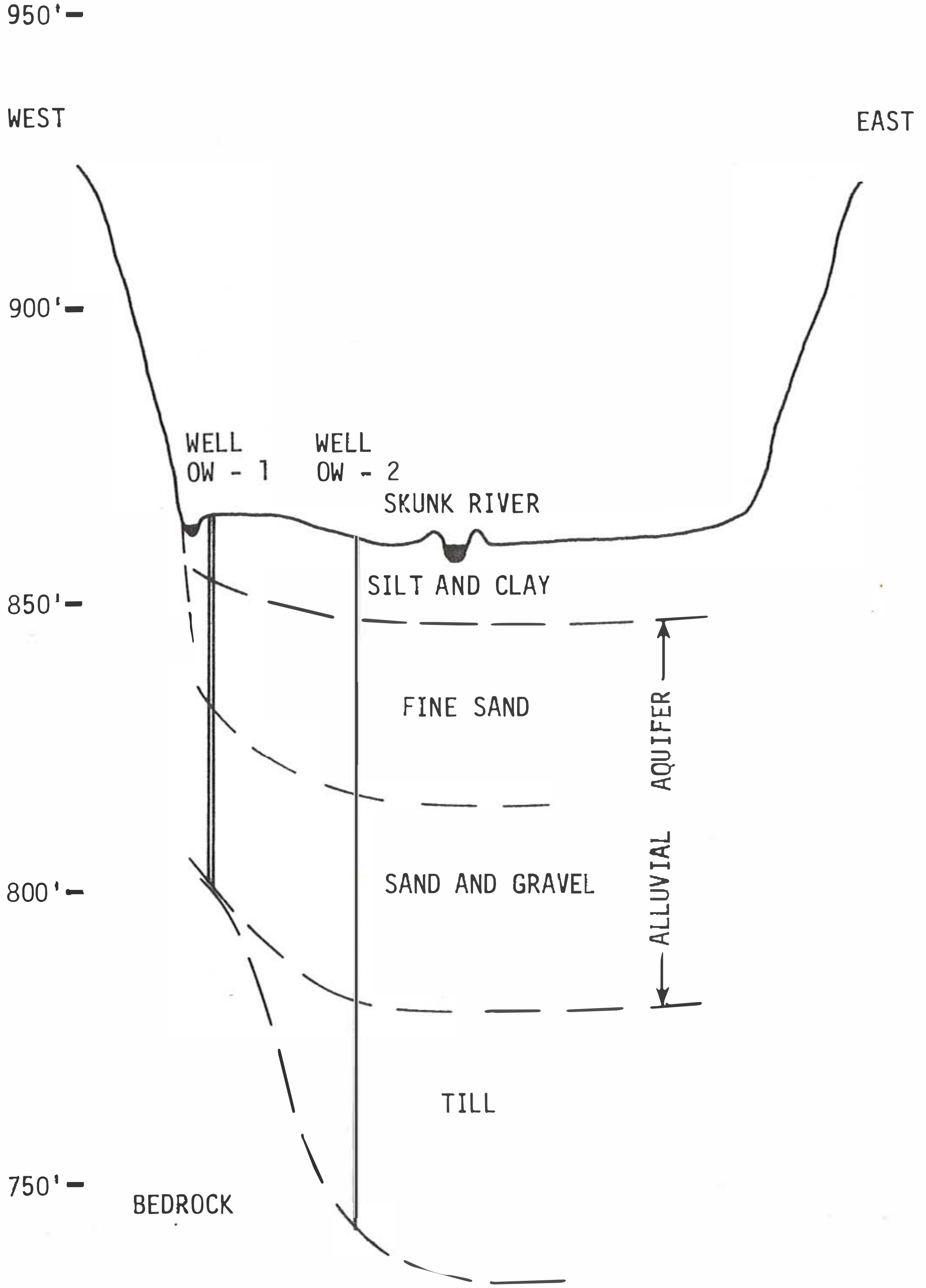



Fig. 4. East-west geologic cross-section through Site #5. Detailed descriptions of the rock units are in the appendices.

Boreholes OW-3 and OW-4 are located on the flood plain between Site 5 and the city of Cambridge. They have the same general stratigraphy as the borehole at Site 5. A surface layer of recent alluvium composed of 20 feet of clay, fine sand, and silty clay overlies 45 to 63 feet of sand, sand with gravel, and gravel. The sands and gravels constitute the buried channel aquifer. The boreholes bottom in till.

The three boreholes (OW-5, OW-6, and OW-7) drilled around the city of Cambridge have a different stratigraphy (Fig. 5). They show a surficial layer 27 to 53 feet thick composed of interbedded till, clay, sand, and sand and gravel. Beneath the surficial layer is 43 to 53 feet of sand, sand and gravel, and gravel. The boreholes bottom in till. The surface layer is interpreted to represent an ice contact complex of meltwater deposited sands interbedded with tills which flowed or slid off the melting glacier into adjacent channels. They are definitely not of an alluvial origin. The underlying sands and gravels are part of the buried channel aquifer.

In summary, the borehole program in the study area demonstrates that the buried channel aquifer extends from Site 5 to the south beyond the city of Cambridge. The aquifer is covered by 12 to 53 feet of fine-grained materials which serve to protect it from surface water contamination.

3.2.1. Ground Water Geology

Two aspects of the ground water flow regimen in the Site 5-Cambridge area must be considered. These are the location and extent of the ground water recharge area and the direction of ground water flow. As already pointed out, previous studies have shown that ground water discharges into

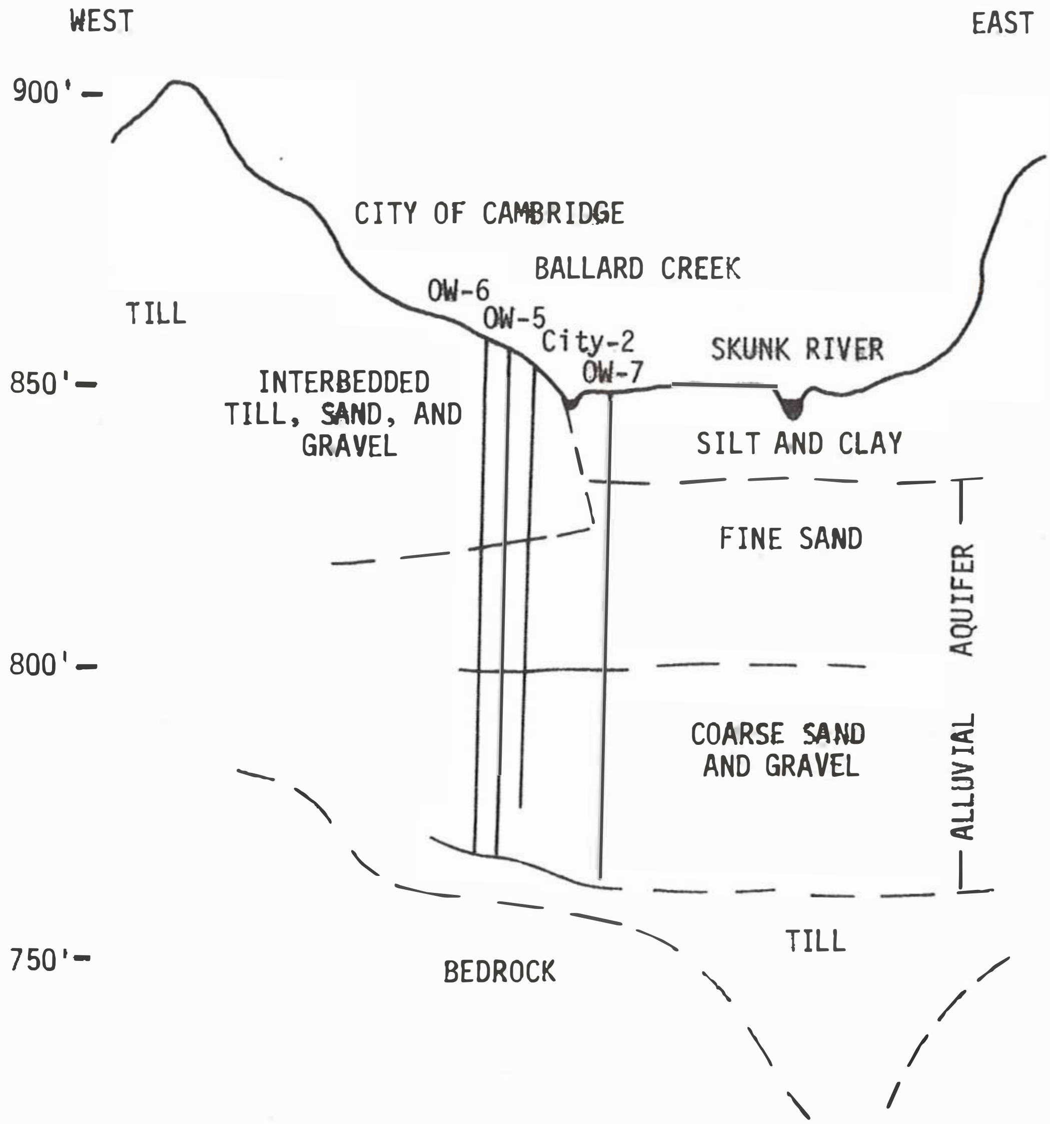



Fig. 5. East-west cross-section through Cambridge. Detailed description of the rock units and stratigraphy in the appendices.

the Skunk River and is derived from local precipitation on the land surfaces (Kent, 1969). This means that the ground water flowing through the buried channel aquifer is derived from both vertical infiltration through the silty alluvium overlying the aquifer and from horizontal inflow of ground water which has infiltrated through the tills of the uplands. The third source of recharge is the bank seepage occurring during river stage increases as a flood wave passes through the study reach. The exact contribution of each source is difficult to determine, but it may be estimated.

To the west of the Site 5-Cambridge area, the upland lying between the Skunk River valley and the ground water divide covers about 33 square miles. The flood plain area overlying the aquifer to the west of the Skunk River in this reach is 3.5 square miles. Although the upland area is almost ten times larger, some of the ground water flow moves to local tributaries and is discharged as base flow to the Skunk River. In addition, the permeability of the upland tills is much less than of the alluvial soils and underlying sands (perhaps less than 1 to 10 percent). This implies that there is ground water flow from upland areas, but that the greatest influence at Site 5 remains the alluvial flood plain and bank seepage from the river during flood periods.

## 3.3. Downstream of Cambridge

A reconnaissance geological and geophysical investigation was conducted south of Cambridge in the Skunk River valley in 1970 and 1971 (Dougal et al., 1971). The geological cross section was taken along Iowa Highway 210. This investigation was made during the period when the

U.S. Army Corps of Engineers was planning for the Ames Reservoir (Dougal et al., 1971). Six test boreholes were drilled along this alignment to ascertain the lithologic characteristics of the Pleistocene glacial drift and the depth to bedrock. A seismic refraction survey also was conducted.

Results, as shown in Fig. 6, illustrate the nature of the glacial deposits in the old bedrock channel. The Ames Buried Channel Aquifer rests on an old till deposit overlying the bedrock. At this location the aquifer consists of 60 feet of fine, medium, and coarse sands, but little gravel. An interfingering relationship is inferred along the eastern and western margins of the aquifer. The modern alluvium represents the upper 20 feet of the aquifer. The surficial, buried channel aquifer and alluvial formations at Cambridge, in general, are similar to the Squaw Creek system at Ames.

Observation wells were developed at the six borehole sites at the Highway 210 site, and observations were made over a 2-year period. These data can be used in interpreting the hydrologic impacts at Site 5 north of Cambridge.

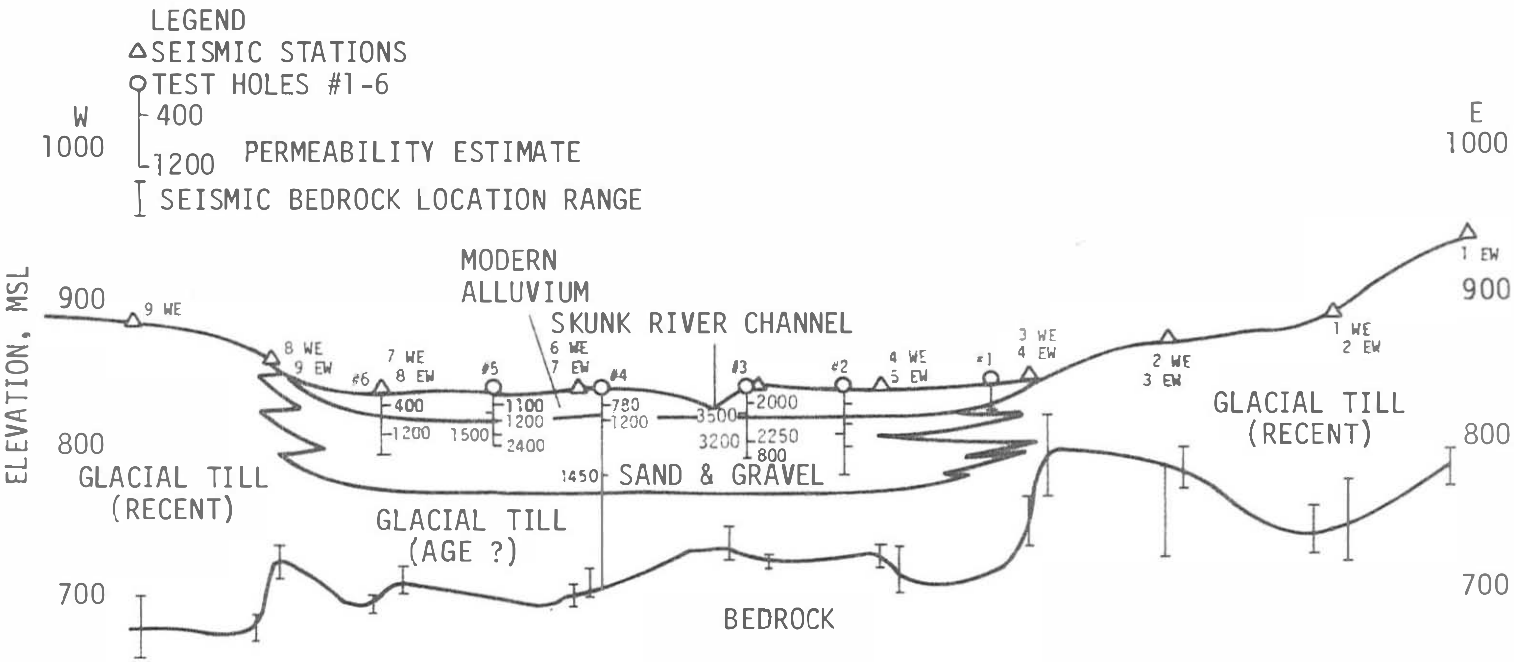



Fig. 6. Cross section at Cambridge, Iowa No. 210

# 4. GROUND WATER MOVEMENT

## 4.1. Ground Water and Surface Water Elevations

Water level observations were obtained at the seven wells installed for this study and of the three Skunk River stations in the study reach. (Data are listed in the Appendices; the results are shown in Fig. 7.) All observation wells have responded to increases in river stages of the Skunk River during the snowmelt period of late March, 1980. This indicates the observation wells are responding satisfactorily and also that the river does have an interconnection with the Ames Buried Channel Aquifer.

The level of the ground water in the seven observation wells and the water levels at the three Skunk River stations provide the data for interpretation of ground water flow patterns in the study area. The data were plotted on a map of the area, and piezometric contours and flow lines were sketched.

## 4.2. Regional Ground Water Regimen

(This section is a review of previous discussion regarding groundwater flow and aquifer recharge.)

Two aspects of the ground water flow regimen in the study area must be considered. These are (1) the location and extent of the ground water recharge area, and (2) the direction of ground water flow. As already pointed out, previous basin studies have shown that ground water discharges into the Skunk River and recharge is derived from local precipitation on the uplands (Kent, 1969) and on the flood plains. This means that the ground water flowing through the buried channel aquifer is derived both from vertical infiltration through the silty alluvium overlying the aquifer and from horizontal inflow of ground

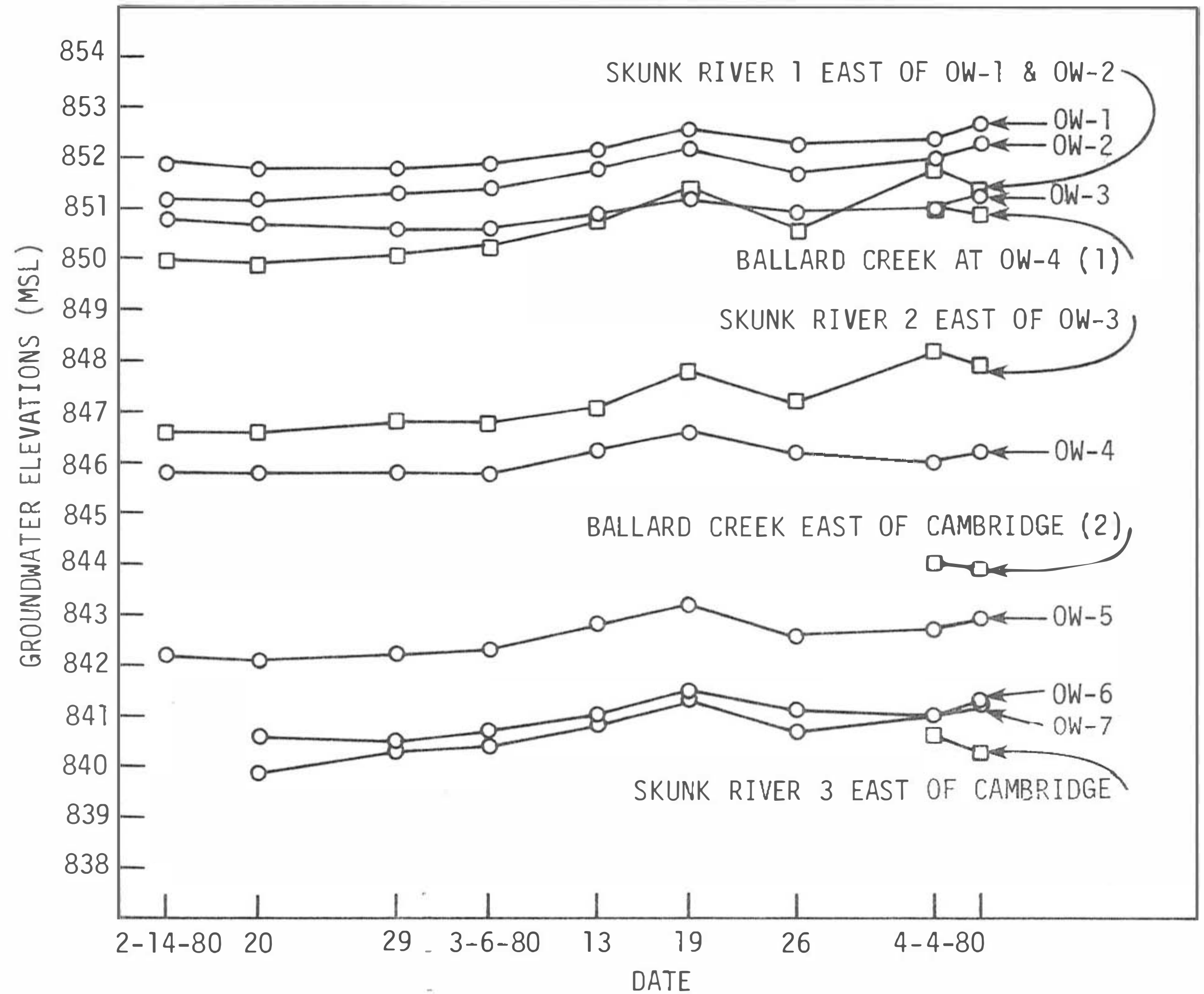



Fig. 7. Graph of groundwater elevations for OW-1 to OW-7 and surface water elevations on the Skunk River and Ballard Creek.

water which has infiltrated slowly through the tills of the uplands. [redacted] is the Skunk River. Extensive mathematical modeling is necessary if the exact contribution of each source is to be determined. When the ground water levels decline below the level of the water in the river, then the river may serve also as a recharge source. Rivers additionally serve as a source of recharge during flood periods. As the stream rises in stage, the ground water levels also rise, but lag behind the streamflow by hours or days. The ground water levels near the Skunk River usually respond in magnitude to a 50 percent value of the river flood stage (Sendlein and Dougal, 1968; Dougal et al., 1971). In other words, a river rise of eight feet would result in the ground water level increasing by four feet close to the river. Once the flood stages fall, the ground water levels begin to decline also.

The upland influence on ground water flows in the valley depends on the size of the ground water drainage area contributing to the aquifer, the permeability of the upland materials, the size of the tributary stream network, and the amount of precipitation received each year. The drainage area lying west of the study area is about 32.5 square miles, and the flood plain area is 3.5 square miles in the study reach. Because the upland glacial till is much less permeable than the valley alluvial sediments, and the tributary streams (i.e., Walnut Creek) intercept some of the regional ground water flow, the net contribution is less than the ten times drainage area factor. Streamflow is the nearest source of recharge, particularly during flood periods. The excess water infiltrating the flood plain soil profile also moves downward to the buried channel aquifer. The amount reaching the aquifer will depend on the infiltration capability at the surface and the soil moisture retention capacity.

## 4.3. Ground Water Flow Patterns

The ground water flow directions must be evaluated over both the long- and short-term. The long-term includes periodic drought effects. As already demonstrated, the long-term annual flow of ground water is from the uplands toward the river. In unconfined aquifers the flow directions can be inferred from the contours on the water table. Because the water table oftentimes mimics the topographic contours, the flow directions can be approximated in a general way from the surface topography; the ground water flow will be perpendicular to the topograhic contour lines. The inferred ground water flow lines in the study area indicate that flow in general is eastward from the uplands and then southeasterly diagonally down valley toward the Skunk River. With this pattern ground water passing under Site 5 would discharge into the Skunk River within a mile downstream.

The short-term ground water flow regimen, during either normal or low flow periods, can be determined from measurements of water table elevations in the boreholes and from measurements of the surface water elevations in the Skunk River. The contour map of the water table as derived from the water elevations measured on April 7, 1980, indicates ground water flow from west to east into the Skunk River. This is presented in Fig. 8. The short-term observations confirm the conclusions derived from the topographic analysis.

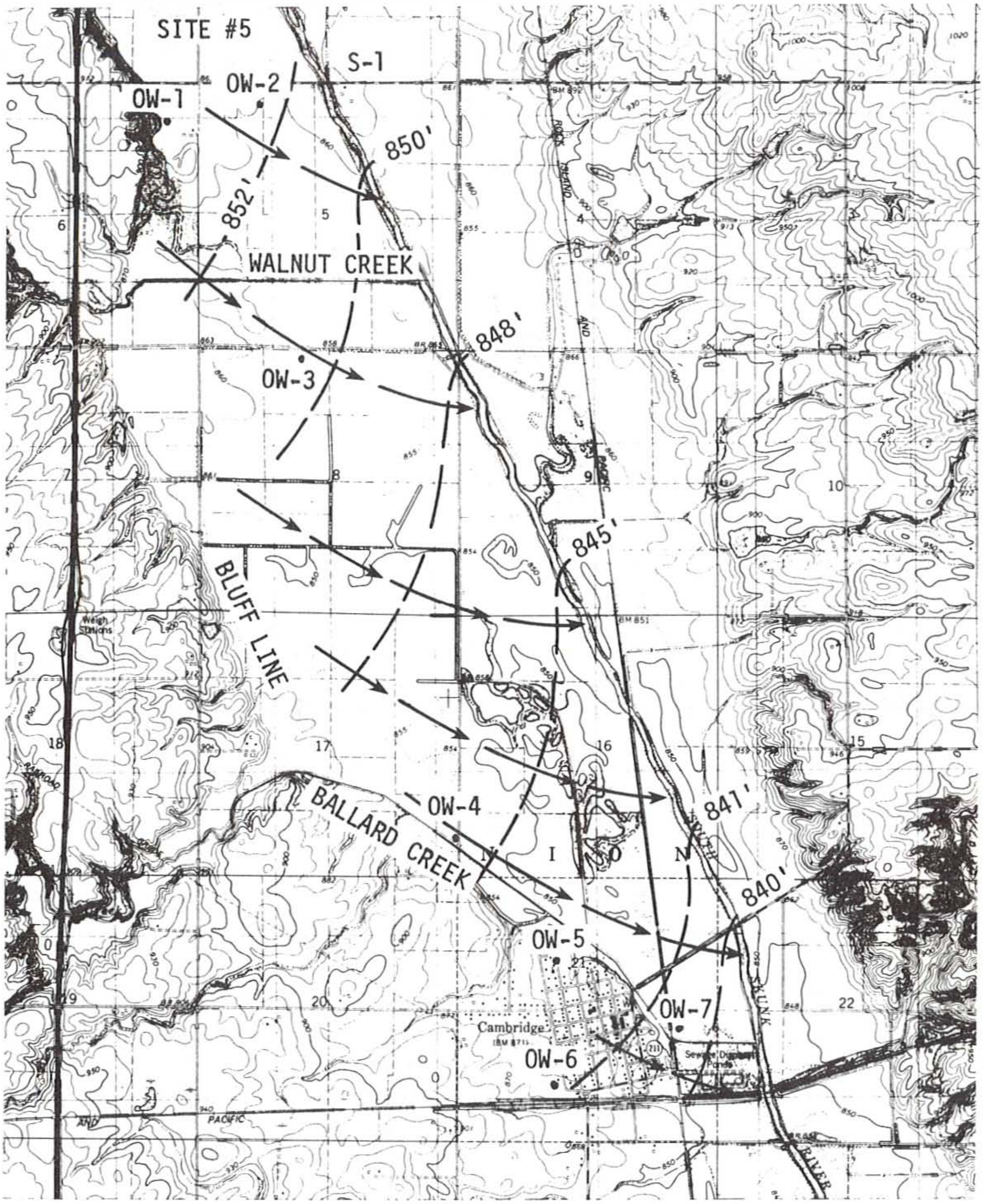



Fig. 8. Ground water table map and hypothesized flow directions as reconstructed from water levels measured on 4-7-80.

The analysis of short-term data indicates that ground water flowing under Site 5 does not pass near the portion of the aquifer from which the water for the city of Cambridge is withdrawn. Based upon the short-term data, the potential for the contamination of the Cambridge ground water supplies by Site 5 appears to be low.

Another aspect of the potential contamination of the aquifer is the depth of penetration of the contaminated water into the aquifer. Numerous studies have shown that the depth of penetration of contaminants into an aquifer is controlled by the local relief and distance from the discharge zone (Sendlein and Palmquist, 1975). Given the low relief of the flood plain and the basic data collected at Site 5, the hydraulic gradient is low and the ground water flow to the river will essentially be parallel to the flood plain surface (see Fig. 9). Analysis of the flow regimen in Fig. 8 suggests that the disposal of digested sludge at Site 5 should be in the areas nearest to the river to allow rapid discharge of any contaminated ground water into the river, where dilution will assist in dissipating any adverse effects.

Studies of the present Ames solid waste disposal site, which is located on the flood plain to the north of Site 5, bear on both the long-and short-term flow directions. A series of monitoring wells were emplaced around the Ames disposal site, and water samples were collected for the years 1972 to 1974 (Packenpaugh, 1973; Stephens, 1974; Palmquist and Sendlein, 1975). The short-term ground water flow, as indicated by water table measurements, is diagonally into the river so that the ground water passing under the disposal site is discharged into the river within one-half mile downstream (Fig. 10). However, the spatial

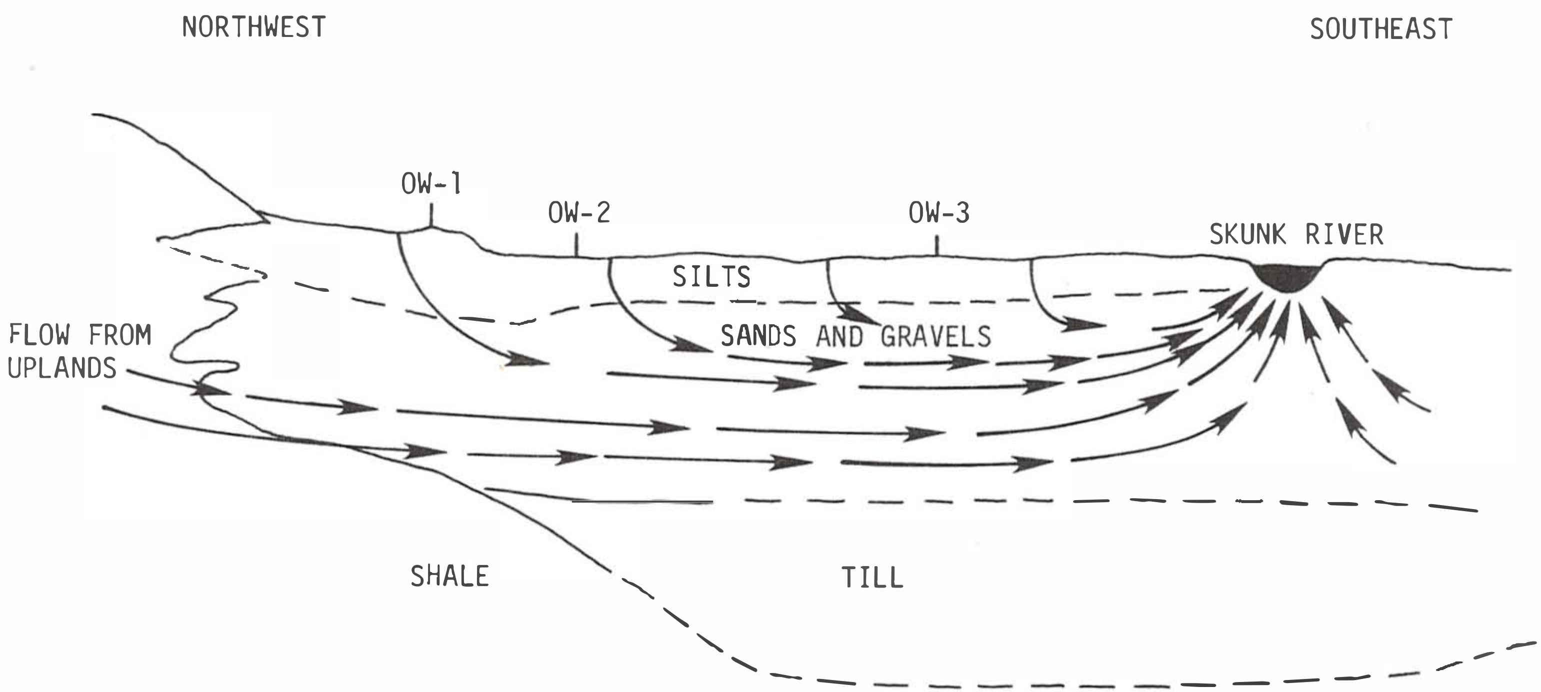



Fig. 9. Hypothetical cross-section through Site 5 illustrating the probable ground water flow lines.

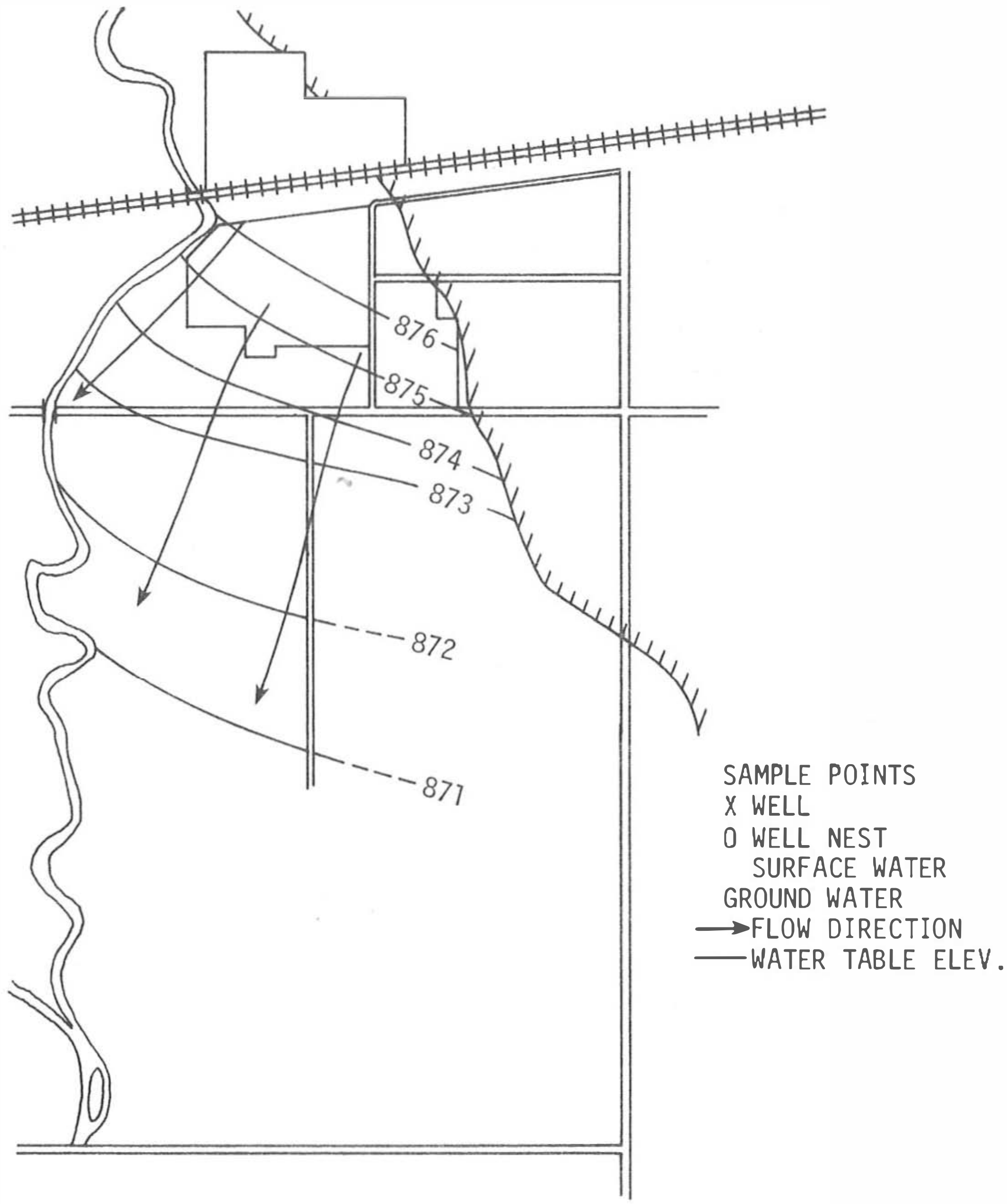



Fig. 10. Ground water flow directions and water table elevations for the years 1972-1974 for the Ames Aquifer in the vicinity of the Ames Disposal Site (after Palmquist and Sendlein, 1975).

distribution of the contaminants in the ground water indicated a long-term down valley flow parallel to the Skunk River (Fig. 11). This study confirms the conclusion of the short-term ground water study at Site 5 but warns that in the long-term, particularly during drought events lasting several years, the ground water flow may have a stronger down valley component.

The results of the ground water study can thus be summarized. The short-term data (normal and low flow periods) indicate that contamination of the Cambridge water supply by activities at Site 5 is unlikely. The longer-term data suggest, during drought periods, that ground water flowing beneath Site 5 may continue down-valley and possibly pass into the withdrawal area of the Cambridge well field. However, little percolation through the flood plain soil profile will occur during these drought events.

In summary, the analysis of the ground water flow at Site 5 indicates that potential for contamination is small, because of the dilution effects and the good soil moisture retention expected from the soil. Any contamination which might occur can be minimized by placing sludge on the flood plain areas nearest the river and minimizing the amounts placed along the bluff areas.

## 4.4. Short-term Flood Impact

Floods aid in recharging alluvial aquifers. The ground water level observations obtained at Iowa Highway 210 illustrate this (Dougal et al., 1971; Dougal and Dueker, 1973). Variations observed in ground water

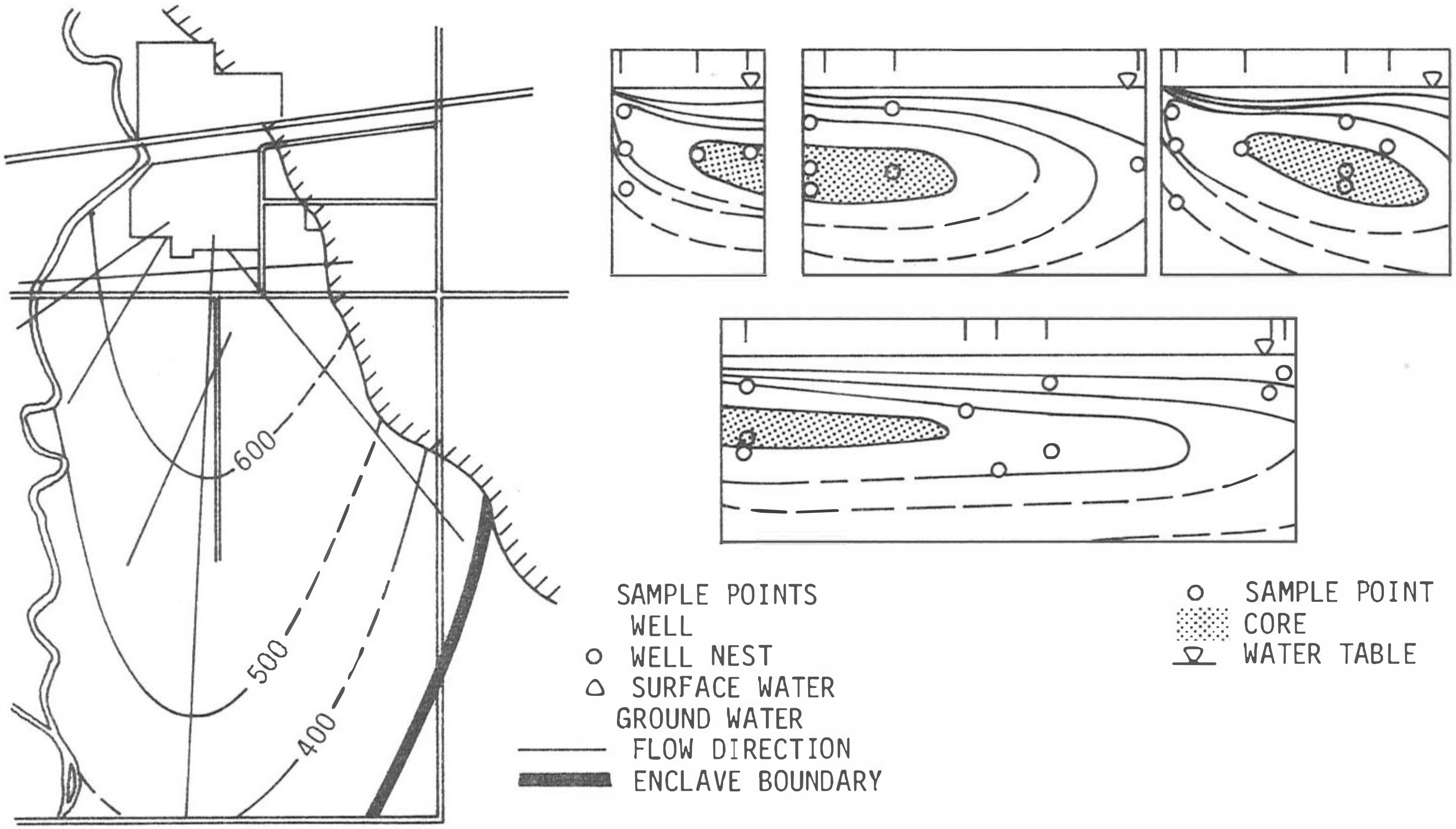



Fig. 11. Map and cross-sectional shape of the enclave of ground water contaminated by the Ames Disposal Site. Note the down valley orientation with respect to the short-term ground water flow directions (after Palmquist and Sendlien, 1975).

levels during flood periods and subsequent low-water periods are shown in Figs. 12 and 13.

The ground water profiles shown in Fig. 12 illustrate the rise in ground water levels during short-term wet periods when the river rose to bank-full stage and precipitation was above normal. The profiles shown in Fig. 13 illustrate the relationships between surface water levels in the stream and ground water levels in the aquifer during the passage of a flood wave. The highest base flows in a stream are believed to be derived from this exhaustion of the short-term bank storage of flood waters which seeped into the alluvial formation.

## 4.5. Summary of Aquifer-River Relationships

The Skunk River serves, therefore, as the discharge sink for the basin, so that both storm surface runoff and ground water flows discharge to the river. During flood periods the piezometric surface rises across the flood plain. During major overbank flooding periods, the entire alluvial depth can become saturated. However, the sand formations in the river bed and in the alluvium prevent movement of particulate matter, including bacteria. Chemicals and other dissolved materials can penetrate to the aquifer during these flood events but are highly diluted during such flood periods. The slow response of ground water wells to increases in river stages results in a maximum ground water response after the flood crest passes. Thereafter, the ground water levels decline and the aquifer discharges seepage flow to the river from the three sources---flood derived bank storage, infiltration and percolation through the flood plain soil profile, and seepage flow from the uplands.

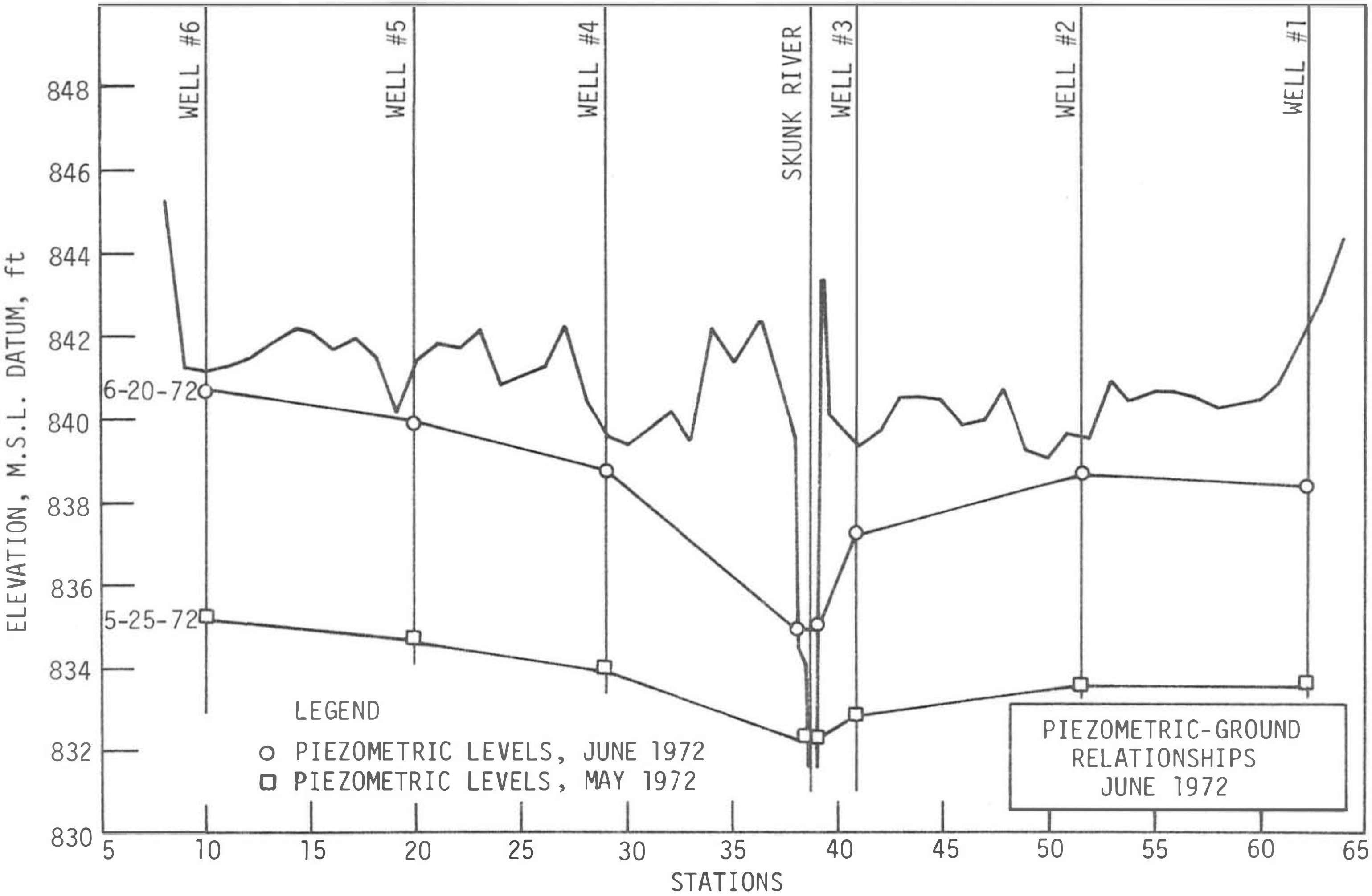



Fig. 12. Groundwater profiles across the Skunk River flood plain, June 1972.

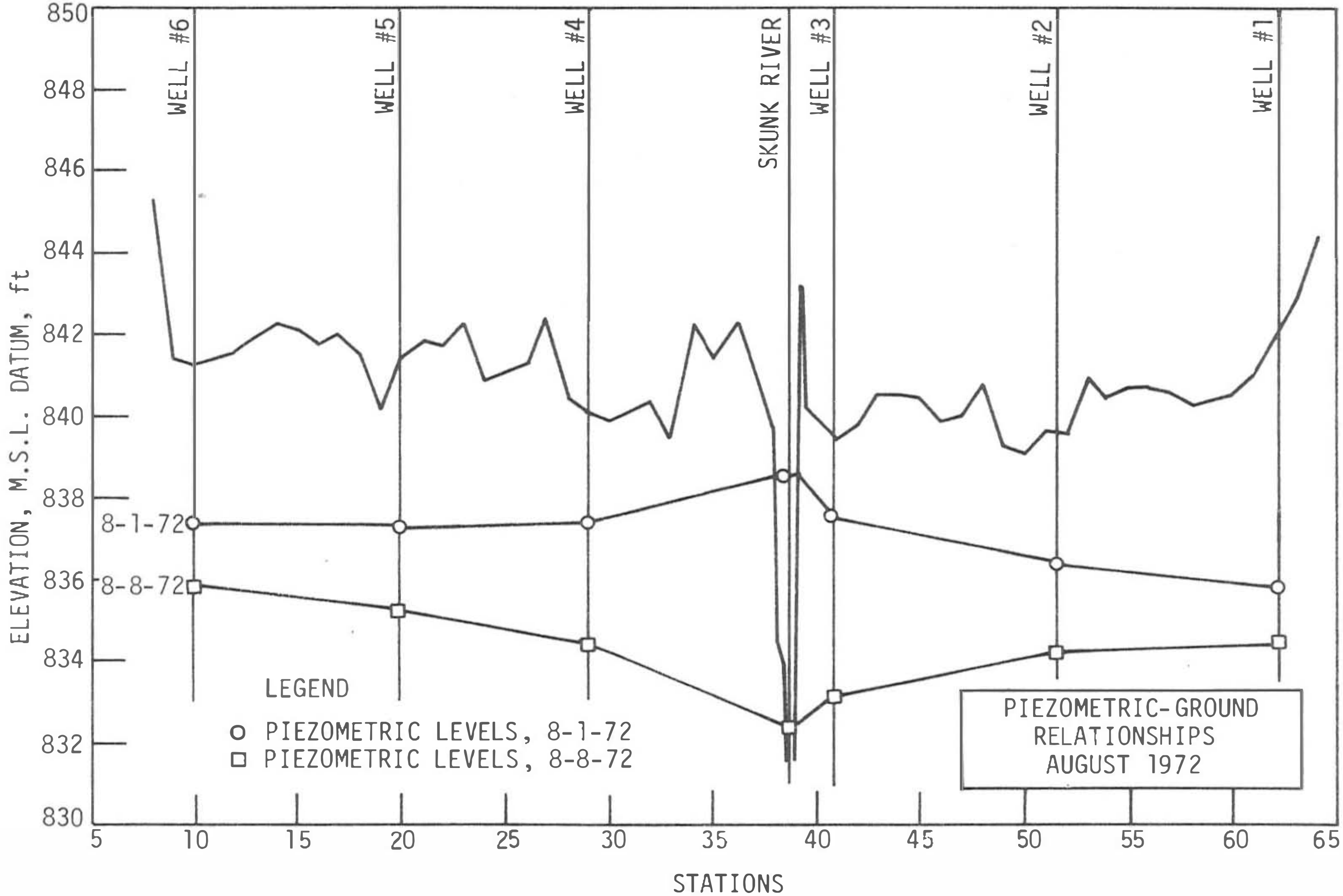



Fig. 13. Groundwater profiles across the Skunk River flood plain, August 1972.

## 4.6. Ground Water Quality

Water quality samples were obtained from each observation well, OW-1 to OW-7. Analyses were made at the Analytical Services Laboratory, Engineering Research Institute. The results are listed in Table 2. Also listed is a raw water sample at the City of Ames well field, analyzed by the Iowa DEQ for EPA compliance. These data show that the water quality in the study area is very similar to that observed at Ames. Iron removal and softening are the key requisites to conditioning this raw water into a potable water satisfactory to Ames consumers.

No data were taken on heavy metals or other toxic elements. These tests are very expensive and time-consuming. Background values at Ames (1977) are below drinking water limits established by the federal EPA. Typical values obtained at Ames (1977 test) were: Barium, 0.4 mg/l; Arsenic, Cadmium, Chromium, Copper, Lead, Selenium, Silver and Zinc, all less than 0.01 mg/l; and Mercury, less than 0.001 mg/l. If Site 5 is selected for use, then these tests should be made.

Table 2. Water quality data for the seven observation wells and for the city of Ames

| Parameter | Water quality levels, in mg/l unless noted | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | OW-1 | OW-2 | OW-3 | OW-4 | OW-5 | OW-6 | OW-7 | City of Ames (raw water) |
| Conductivity (μ mhos/cm) | 846 | 745 | 732 | 879 | 869 | 754 | 803 | 770 |
| pH (pH units) | 7.9 | 7.9 | 8.0 | 8.0 | 8.0 | 7.9 | 7.9 | 7.1 |
| Sol Iron | 0.06 | 0.03 | 0.05 | LT0.03 | LT0.03 | LT0.03 | LT0.03 | - |
| Tot Iron | 13.0 | 5.7 | 3.92 | 1.26 | 5.2 | 6.4 | 7.1 | 6.8 |
| Silicia | 25.7 | 27.7 | 19.8 | 11.1 | 24.9 | 21.4 | 24.6 | 27 |
| Sus Solids | 113 | 39 | 64 | 106 | 127 | 132 | 99 | - |
| Tot Solids | 674 | 547 | 547 | 660 | 688 | 591 | 637 | 519 |
| Hardness(ca) | 277 | 252 | 232 | 190 | 259 | 226 | 252 | - |
| Hardness-Tot | 426 | 379 | 358 | 320 | 405 | 364 | 382 | 414 |
| Phenol Alkalinity | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tot Alkalinity | 349 | 312 | 289 | 288 | 277 | 296 | 315 | 286 |
| Tot Potassium | 4.4 | 1.4 | 1.3 | 3.0 | 2.4 | 1.8 | 1.7 | 3.6 |
| Tot Calcium | 143 | 120 | 107 | 103 | 120 | 108 | 121 | 100 |

Table 2. Continued

| Parameter | Water quality levels, in mg/l unless noted | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | OW-1 | OW-2 | OW-3 | OW-4 | OW-5 | OW-6 | OW-7 | City of Ames (raw water) |
| Tot Magnesium | 38.9 | 35.8 | 32.8 | 33.5 | 36.5 | 33.0 | 34.8 | 35 |
| Tot Manganese | 0.41 | 0.16 | 0.22 | 0.24 | 0.57 | 0.47 | 0.51 | 0.22 |
| $NO_3$-$NO_2$-N | 0.32 | 0.08 | 0.18 | 2.14 | 0.10 | 0.11 | 0.09 | 0.1± |
| $F^-$* | 0.11 | 0.23 | 0.23 | 0.31 | 0.18 | 0.14 | 0.17 | 0.3 |
| Chloride | 31 | 12.7 | 22 | 57 | 55 | 14 | 24 | 27 |

*$F^-$ activity, not total fluoride

# 5. FLOOD IMPACT

## 5.1. Background Information

Site 5 is located on the flood plain of the Skunk River. General topographic features and levee and drainage data were discussed in an earlier section of this report. The facility site is located in an area near the bluff which is at a higher elevation (Elevation 862 to 863) than the lowest areas of the flood plain (Elevation 858±). The old channel of the river meanders through the farmland and is at the west bluff at Site 5.

## 5.2. Flood History

The flood of record occurred in June 1975, with a peak discharge of 14,700 cubic feet per second (cfs) at the South Sixteenth Street gaging station. A detailed report, which was prepared by the U.S. Geological Survey (Lara and Heinitz, 1976), is available. The magnitude and frequency of floods on the Squaw Creek and the Skunk River at Ames are included in the report. The flood profile data extend downstream to the I-35 bridge, just upstream of Site 5.

## 5.3. Analysis for Site 5

The results obtained at Ames were reviewed, and those data applicable to Site 5 were used to make an initial appraisal of the flood risk at the site. Appropriate hydrologic adjustments were made for the change in drainage area and stream slope from Ames to Site 5. A square root relationship of drainage areas and stream slopes was used to increase the magnitude and stage of floods at Site 5 and in translating stagedischarge relationships at Ames to Site 5. The results are listed in Table 3.

These are preliminary results and should be verified by additional hydraulic studies if Site 5 is selected. Additional flood stage data for the 1975 flood could be obtained from the county, the State, U.S.G.S., and the U.S. Army Corps of Engineers. The results listed above conform to photos and other observation data provided at the public hearings.

The 1975 flood was slightly greater than the one hundred year flood discharge magnitude. Therefore, it can serve as the flood risk criteria at Site 5 to meet state, Iowa Natural Resources Council (INRC), and Federal Emergency Management Agency (FEMA) regulatory requirements. Construction of flood protection measures, as well as occupancy of the site, will require permits from the INRC. Still true?

## 5.4. Flood Protection

Facilities at Site 5 must be protected against flooding. The most cost effective method is to elevate and flood proof the plant site and the buildings and units constructed at the site. High damage facilities or those with greatest impact on operating schedules, such as the administration and laboratory facilities, can be placed in the bluff area west of the old channel and north of the east-west county road at Site 5.

The land areas to be used for disposal of digested sludge can be protected by levees. Continuing use of the existing agricultural

Table 3. Flood magnitudes, frequencies, and stages at Site 5.

| Recurrence Interval | Estimated Peak Discharge at Ames, cfs | Estimated Peak Discharge at Site 5, cfs | Stage for Peak Discharge in feet Mean Sea Level at Site 5 |
|---|---|---|---|
| 2-year | 4,750 | 4,900 | 860-861 |
| 5-year | 7,370 | 7,600 | 862-863 |
| 10-year | 9,050 | 9,300 | 863-864 |
| 25-year | 11,000 | 11,300 | 864-864.5 |
| 50-year | 12,500 | 12,800 | 865-865.5 |
| 100-year | 13,800 | 14,160 | 866-867 |

levees or a need for levee relocation and reconstruction will have to be evaluated and coordinated with the Iowa Natural Resources Council. Interior drainage and protection from backup of high river stages through the Walnut Creek drainage outlet will have to be included in the project design phase.

## 6. ACKNOWLEDGMENTS

The ground water studies for the Ames-Cambridge reach of the Skunk River were conducted at the request of the city of Ames. Because Iowa State University contributes a substantial percentage of the waste water flow to the municipal Water Pollution Control Plant, it also is involved in the improvements required for water pollution control. The study was conducted through the support facilities of the Engineering Research Institute, College of Engineering. Additional support and coordination were provided by the Department of Civil Engineering, the Iowa State Water Resources Research Institute, and its federal counterpart, the Office of Water Research and Technology (OWRT), U.S. Dept. of Interior. Several state and federal agencies contributed data for the study, including the Iowa Department of Transportation, Iowa Natural Resources Council, Iowa Department of Environmental Quality, the U.S. Geological Survey, and the U.S. Army Corps of Engineers, (Rock Island District).

Field investigations were carried out by three graduate research assistants, Bryant Berg and Vern Schaefer in Civil Engineering and Bruce Bohlken in Earth Sciences. Their diligent efforts, including wintertime surveys, are much appreciated. The field test borehole drilling and sieve analyses were performed by the Layne-Western Company, Ames, Iowa. Their attention and consistent efforts to produce the requested results during the wintertime drilling operation also are much appreciated and their advisory services acknowledged. The Story County Engineer's Office gave approval for the drill sites along county roads.

The support of the ground water research program by the City Council, City of Ames, over the 1964 to 1980 period is also acknowledged. Coordination with the City of Ames was accomplished through the efforts of Tom Neuman, Assistant Director, and Dr. Harris Seidel, Director, of the Ames Water and Wastewater Treatment Facilities. The cooperation of the City Council at Cambridge, through the mayor and council members, is also acknowledged. Permission was granted to drill and install observation wells OW-5, OW-6, and OW-7 in the city.

The assistance of Mrs. Emmy Epperson in typing the progress reports, hearing documents, and the advance copy of the final report is gratefully appreciated and acknowledged. The amount of material included in this report reflects on the importance of the subject and the complexities of the real world today.

Because of the multiple sources of data and the input from the four faculty investigators, the editor assumes full responsibility for technical and editorial changes necessary to complete this report. The opportunity to share views among the participants has aided all in gaining a better understanding of the occurrence, distribution, and movement of surface and ground waters in the Skunk River basin.

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# 8. APPENDICES

Appendix A. Cambridge Ground Water Summary

Appendix B. Study of Grain Size Distribution, OW-1 and OW-2

Appendix C. Borehole Stratigraphic Data, Boreholes OW-1 through OW-7 and City of Cambridge

# APPENDIX A

## Cambridge Ground Water Summary

### Ground Water Elevations

| Date | OW-1 | OW-2 | OW-3 | OW-4 | OW-5 | OW-6 | OW-7 |
|---|---|---|---|---|---|---|---|
| 2-14-80 | 851.9 | 851.2 | 850.8 | 845.8 | 842.2 | -- | -- |
| 2-20-80 | 851.8 | 851.2 | 850.7 | 845.8 | 842.1 | 840.6 | 839.9 |
| 2-29-80 | 851.8 | 851.3 | 850.6 | 845.8 | 842.2 | 840.5 | 840.3 |
| 3-6-80 | 851.9 | 851.4 | 850.6 | 845.8 | 842.3 | 840.7 | 840.4 |
| 3-13-80 | 852.2 | 851.8 | 850.9 | 846.2 | 842.8 | 841.0 | 840.8 |
| 3-19-80 | 852.6 | 852.2 | 851.2 | 846.6 | 843.2 | 841.5 | 841.3 |
| 3-26-80 | 852.3 | 851.7 | 850.9 | 846.2 | 842.6 | 841.1 | 840.7 |
| 4-4-80 | 852.4 | 852.0 | 851.0 | 846.0 | 842.7 | 841.0 | 841.0 |
| 4-7-80 | 852.7 | 852.3 | 851.3 | 846.2 | 842.9 | 841.3 | 841.2 |

### Ground Elevations

| OW-1 | OW-2 | OW-3 | OW-4 | OW-5 | OW-6 | OW-7 |
|---|---|---|---|---|---|---|
| 862.0 | 858.4 | 858.4 | 854.4 | 863.9 | 868.1 | 847.9 |

### Surface Water Elevations

| Date | Skunk 1* | Skunk 2* | Skunk 3* | Ballard Creek at OW-4 | Ballard Creek East of Cambridge |
|---|---|---|---|---|---|
| 2-14-80 | 850.0 | 846.6 | -- | -- | -- |
| 2-20-80 | 849.9 | 846.6 | -- | -- | -- |
| 2-29-80 | 850.1 | 846.8 | -- | -- | -- |
| 3-6-80 | 850.3 | 846.8 | -- | -- | -- |
| 3-13-80 | 850.8 | 847.1 | -- | -- | -- |
| 3-19-80 | 851.4 | 847.8 | -- | -- | -- |
| 3-26-80 | 850.6 | 847.2 | 838.4 | -- | -- |
| 4-4-80 | 851.8 | 848.2 | 840.6 | 851.0 | 844.0 |
| 4-7-80 | 851.4 | 847.9 | 840.2 | 850.9 | 843.9 |

-- Indicates no data collected.

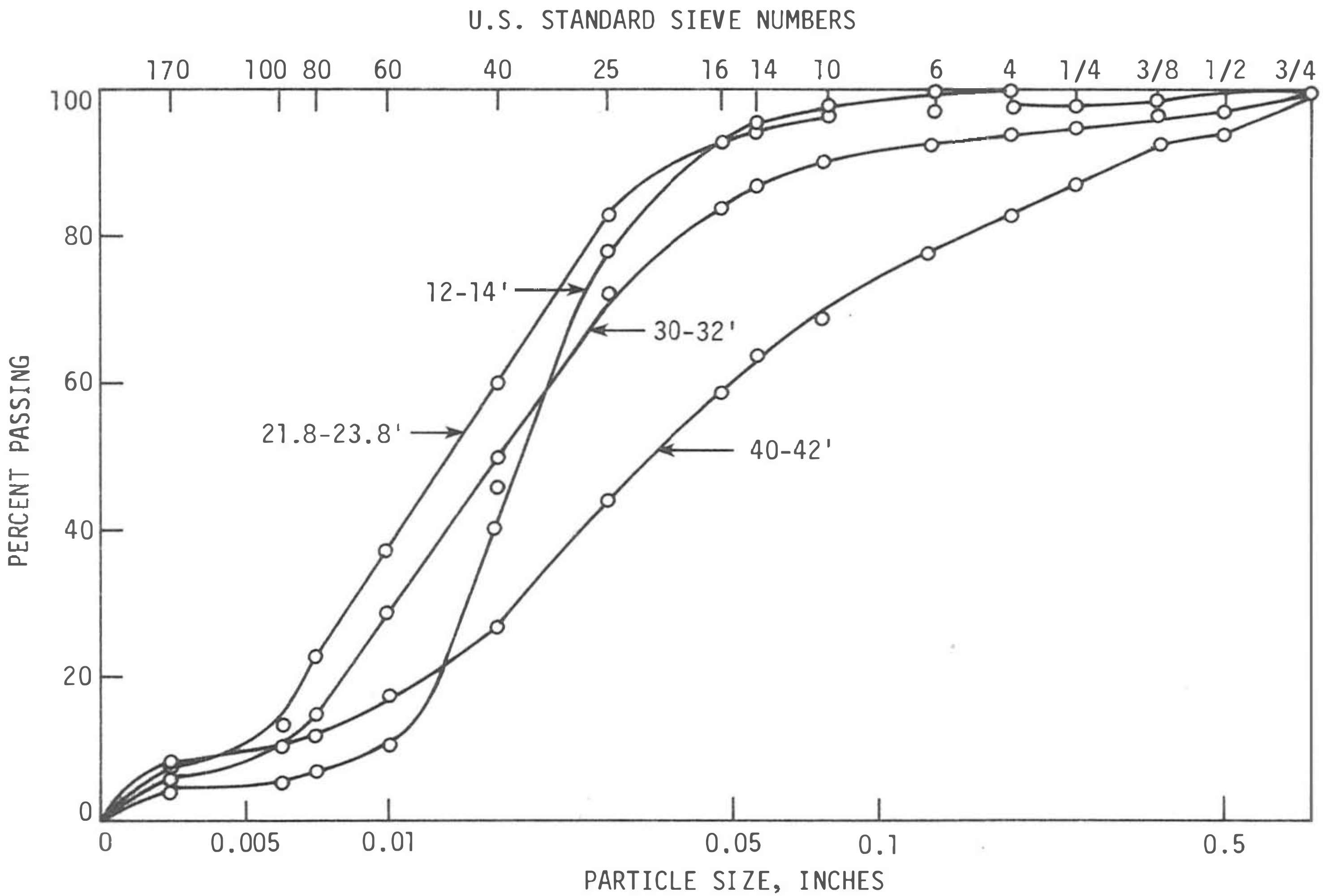
* Skunk 1 - East of OW-1 and OW-2
Skunk 2 - East of OW-3
Skunk 3 - East of OW-7

APPENDIX A Continued

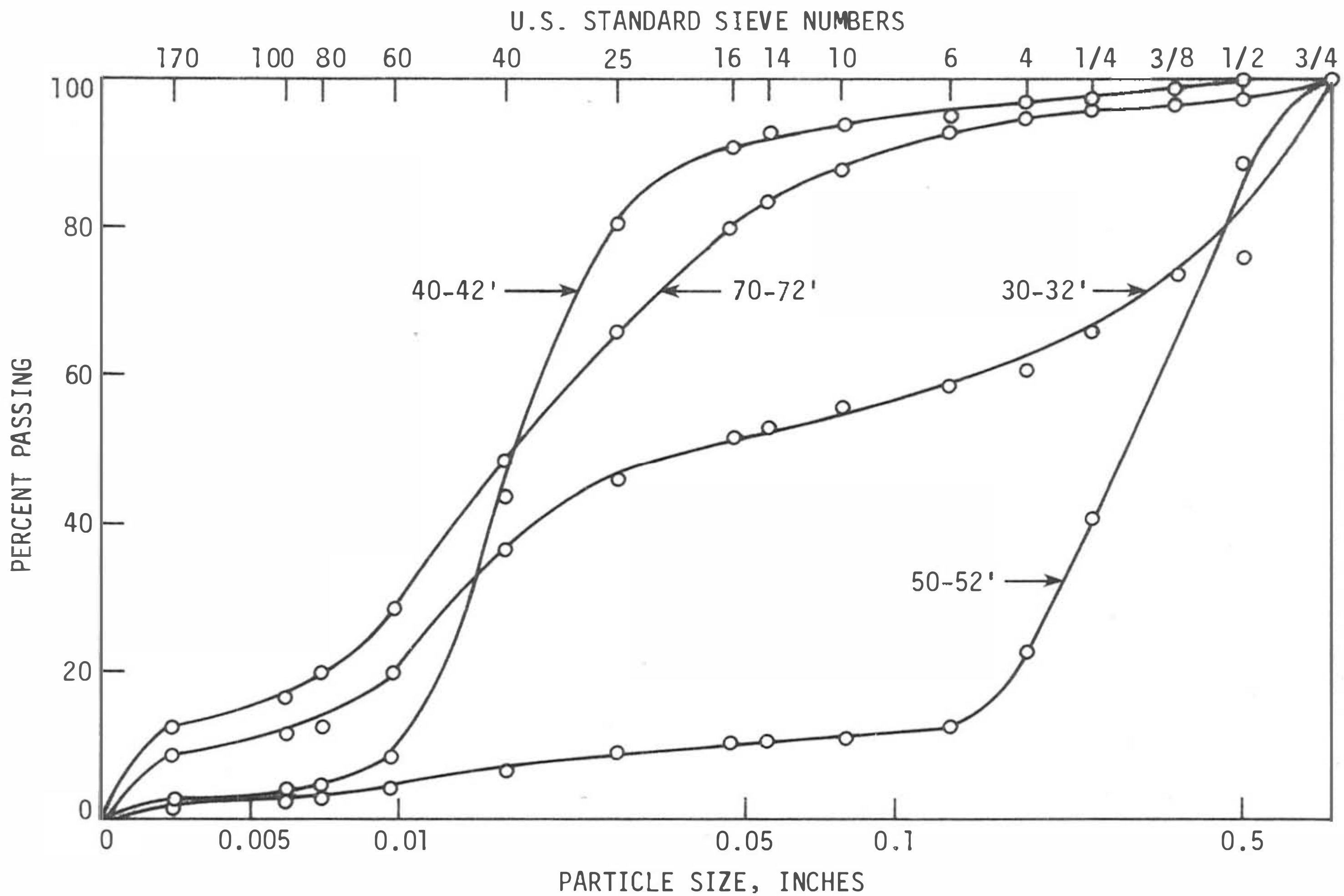
Site Locations

| Site | Distance |
|---|---|
| OW-1 to OW-2 | 1,950' |
| OW-1 to Skunk 1 | 3,250' |
| OW-1 to OW-3 | 6,250' |
| OW-2 to Skunk 1 | 1,300' |
| OW-2 to OW-3 | 5,450' |
| Skunk 1 to Skunk 2 | 6,100' |
| OW-3 to OW-4 | 10,200' |
| OW-4 to OW-5 | 3,200' |
| OW-5 to OW-6 | 2,550' |
| OW-5 to OW-7 | 2,100' |
| Skunk 2 to Skunk 3 | 12,700' |

Distances scaled from Huxley, Iowa Quadrangle




APPENDIX B. GRAIN SIZE DISTRIBUTION, OW-1.



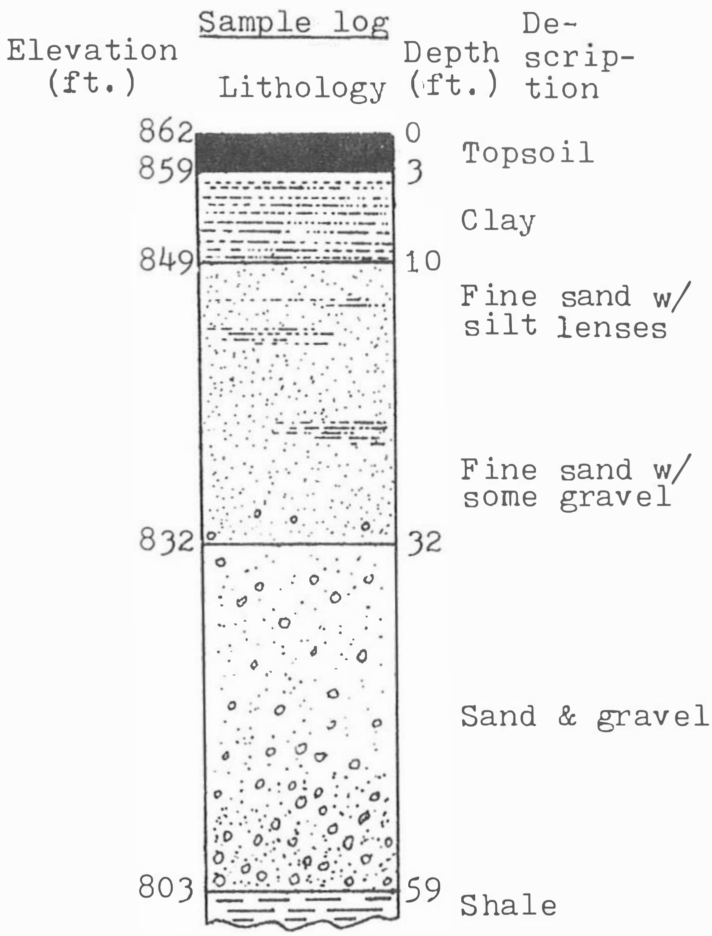

APPENDIX B. GRAIN SIZE DISTRIBUTION, OW-2.

# APPENDIX C

## Borehole Stratigraphic Data, Borehole OW-1

| Depth Below Surface, Feet | | |
|---|---|---|
| From | To | Formation Description |
| 0 | 3.0 | Black topsoil |
| 3.0 | 9.0 | Blackish brown clay |
| 9.0 | 10.0 | Brown fine clayey sand |
| 10.0 | 12.0 | Grayish brown fine sand |
| 12.0 | 24.8 | Gray clayey sand with silt seams |
| 24.8 | 32.0 | Gray fine sand with some gravel |
| 32.0 | 52.0 | Gray sand with gravel |
| 52.0 | 58.8 | Brown sand with gravel |
| 58.8 | 60.3 | Weathered or broken rock |
| 60.3 | 61.3 | Blue-gray shale |

OW-1 (NE/NE Section 6, T82N, R23W).



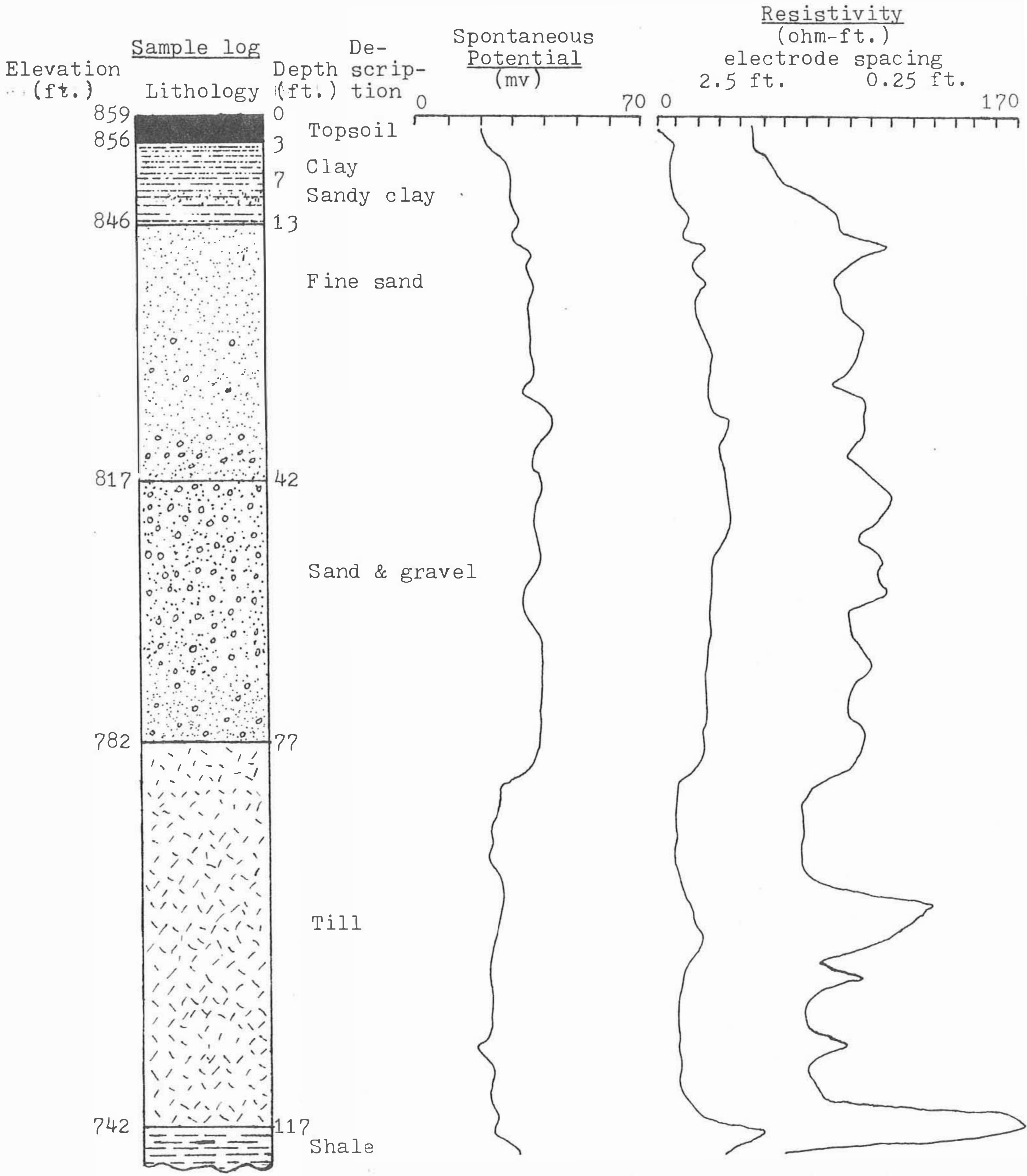

Vertical scale: 1" = 15'

# APPENDIX C

## Borehole Stratigraphic Data, Borehole OW-2

| Depth Below Surface, Feet | | |
|---|---|---|
| From | To | Formation Description |
| 0 | 3 | Black topsoil |
| 3 | 7 | Black clay (gumbo) |
| 7 | 8 | Brown sandy clay |
| 8 | 12.5 | Gray clay |
| 12.5 | 20.0 | Gray sand with small gravel |
| 20.0 | 40.0 | Gray sand with medium to large gravel |
| 40.0 | 42.0 | Fine gray sand |
| 42.0 | 50.0 | Gray sand with medium to large gravel |
| 50.0 | 60.4 | Gray sand with medium to large gravel |
| 60.4 | 77.2 | Gray medium to fine sand with very little gravel |
| 77.2 | 116.5 | Black glacial till |
| 116.5 | 121.0 | Broken rock and black shale |

OW-2 (NE/NW Section 5, T82N, R23W).




Vertical scale: 1" = 15'

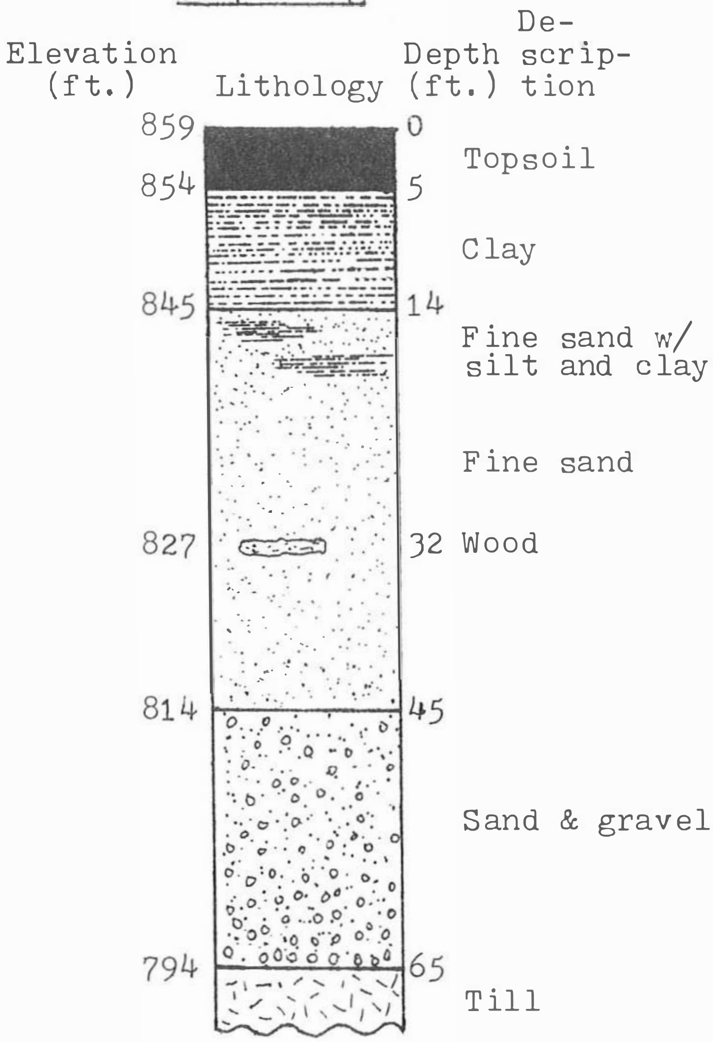
# APPENDIX C

## Borehole Stratigraphic Data, Borehole OW-3

| Depth Below Surface, Feet From | To | Formation Description |
|---|---|---|
| 0 | 4.5 | Black topsoil |
| 4.5 | 12 | Yellow clay |
| 12 | 14 | Light grayish green clay |
| 14 | 20 | Fine yellow sand with yellowish green silty clay |
| 20 | 25 | Fine yellowish brown sand and gravel |
| 25 | 30 | Brownish yellow sand and gravel-fine to medium |
| 30 | 35 | Sand and gravel with coal lenses at 32' |
| 35 | 40 | Sand and gravel - turning gray - medium to fine |
| 40 | 45 | Sand and gravel - gray - medium to coarse |
| 45 | 50 | Gray sand and gravel - medium to coarse with gravel becoming more coarse - cobbles numerous |
| 50 | 55 | Gray sand and gravel - medium to coarse with cobbles |
| 55 | 60 | Sand and gravel - gray - coarse with cobbles |
| 60 | 64.5 | Sand and gravel - gray - very coarse with cobbles |
| 64.5 | 70 | Dark gray till |

OW-3 (NE/NE/NW Section 8, T82N, R23W).

Sample log



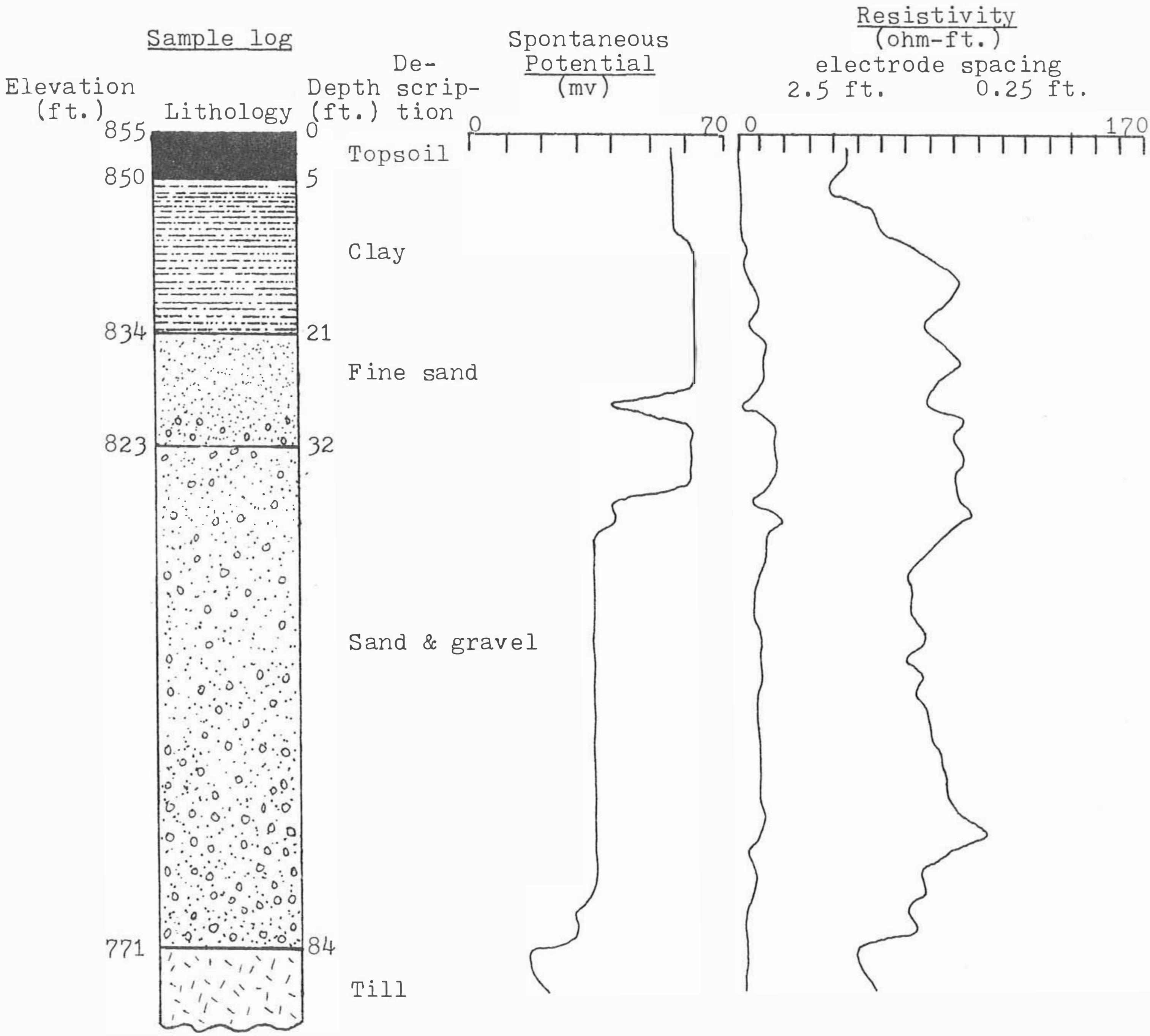

Vertical scale: 1" = 15'

# APPENDIX C

## Borehole Stratigraphic Data, Borehole OW-4

| Depth Below Surface, Feet From | To | Formation Description |
|---|---|---|
| 0 | 5 | Black topsoil |
| 5 | 12 | Brown clay |
| 12 | 20.5 | Blue clay |
| 20.5 | 21.5 | Fine brown sand |
| 21.5 | 25.0 | Fine brown sand with some gravel |
| 25.0 | 32.0 | Brown sand - fine to medium |
| 32.0 | 65.0 | Gray sand fine to medium with small and large gravel |
| 65.0 | 83.5 | Brown sand with small and large gravel |
| 83.5 | 91.2 | Glacial till (dark gray) |

OW-4 (SE/SE Section 17, T82N, R23W).




Vertical scale: 1" = 15'

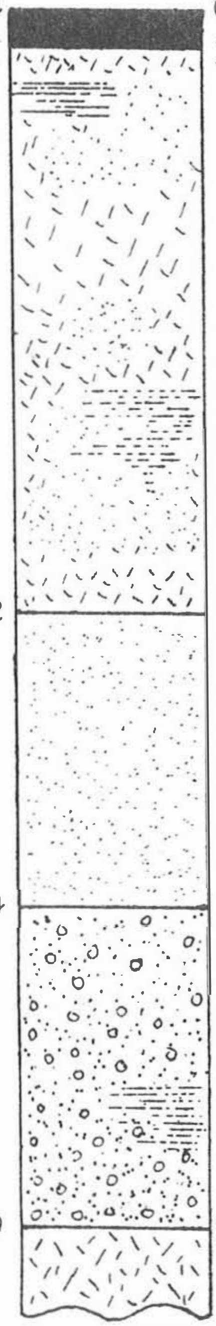
# APPENDIX C

## Borehole Stratigraphic Data, Borehole OW-5

| Depth Below Surface, Feet | | |
|---|---|---|
| From | To | Formation Description |
| 0 | 3 | Black topsoil |
| 3 | 3.5 | Muddy brown till |
| 3.5 | 4 | Brownish yellow clay |
| 4 | 7 | Brownish yellow sand - fine |
| 7 | 26 | Blue clay |
| 26 | 30 | Gray sand and gravel - fine |
| 30 | 33 | Gray sand and gravel - fine to medium |
| 33 | 38 | Blue gray till with gravel |
| 38 | 42 | Very fine grayish white sand - hard |
| 42 | 47 | Dark gray till |
| 47 | 60 | Sand and gravel - gray - fine |
| 60 | 70 | Sand and gravel - gray - fine to medium |
| 70 | 75 | Gray sand and gravel - medium to coarse |
| 75 | 80 | Gray sand and gravel - coarse |
| 80 | 87 | Sand and gravel - coarse with cobbles |
| 87 | 88.5 | Brownish yellow clay |
| 88.5 | 90 | Gravel - brownish yellow |
| 90 | 92 | Layered gravel and gray till with cobbles |
| 92 | 95 | Dark gray till with cobbles |
| 95 | 101.5 | Dark gray till |

OW-5 (NE/SW Section 21, T82N, R23W).

Sample log



| Elevation (ft.) | Lithology | Depth (ft.) | Description |
|---|---|---|---|
| 864 | | 0 | Topsoil |
| 861 | | 3 | Interbedded till, silt, clay, sand and gravel |
| 822 | | 42 | Fine sand |
| 794 | | 70 | Sand & gravel<br>Clay<br>Sand & gravel |
| 769 | | 95 | Till |

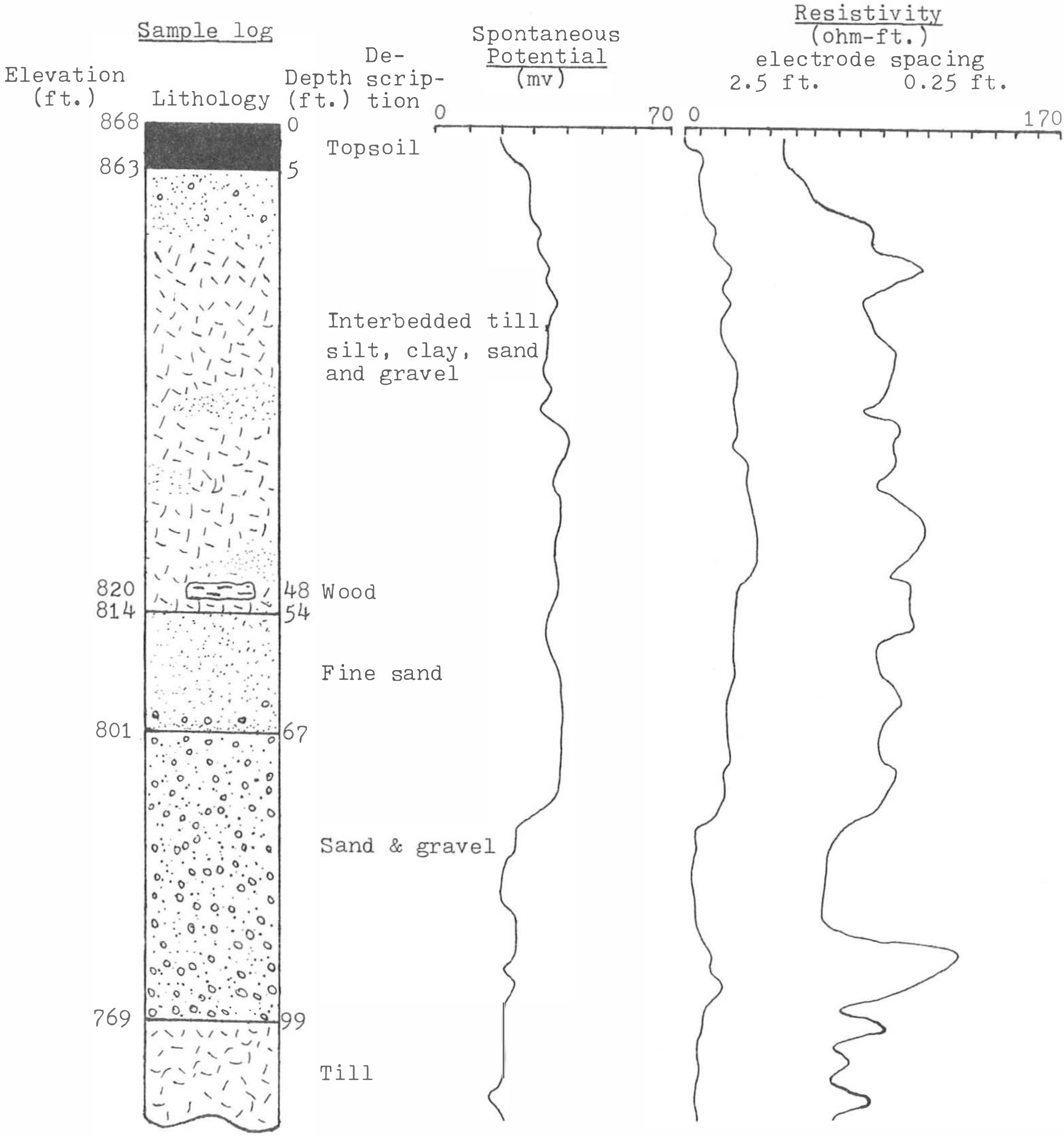
Vertical scale: 1" = 15'

# APPENDIX C

## Borehole Stratigraphic Data, Borehole OW-6

| Depth Below Surface, Feet | | |
|---|---|---|
| From | To | Formation Description |
| 0 | 5 | Black topsoil |
| 5 | 6 | Brown clayey sand |
| 6 | 12.5 | Brown medium sand with small gravel |
| 12.5 | 44.3 | Gray till |
| 44.3 | 47.8 | Gray medium sand with small gravel |
| 47.8 | 48.3 | Gray till |
| 48.3 | 53.8 | Gray till, coal, wood |
| 53.8 | 66.5 | Gray fine to medium sand with some gravel |
| 66.5 | 67.0 | Brown very fine silty sand |
| 67 | 98.8 | Brown medium to large sand with medium to large gravel |
| 98.8 | 110.0 | Gray till |

OW-6 (SE/SW Section 21, T82N, R23W).



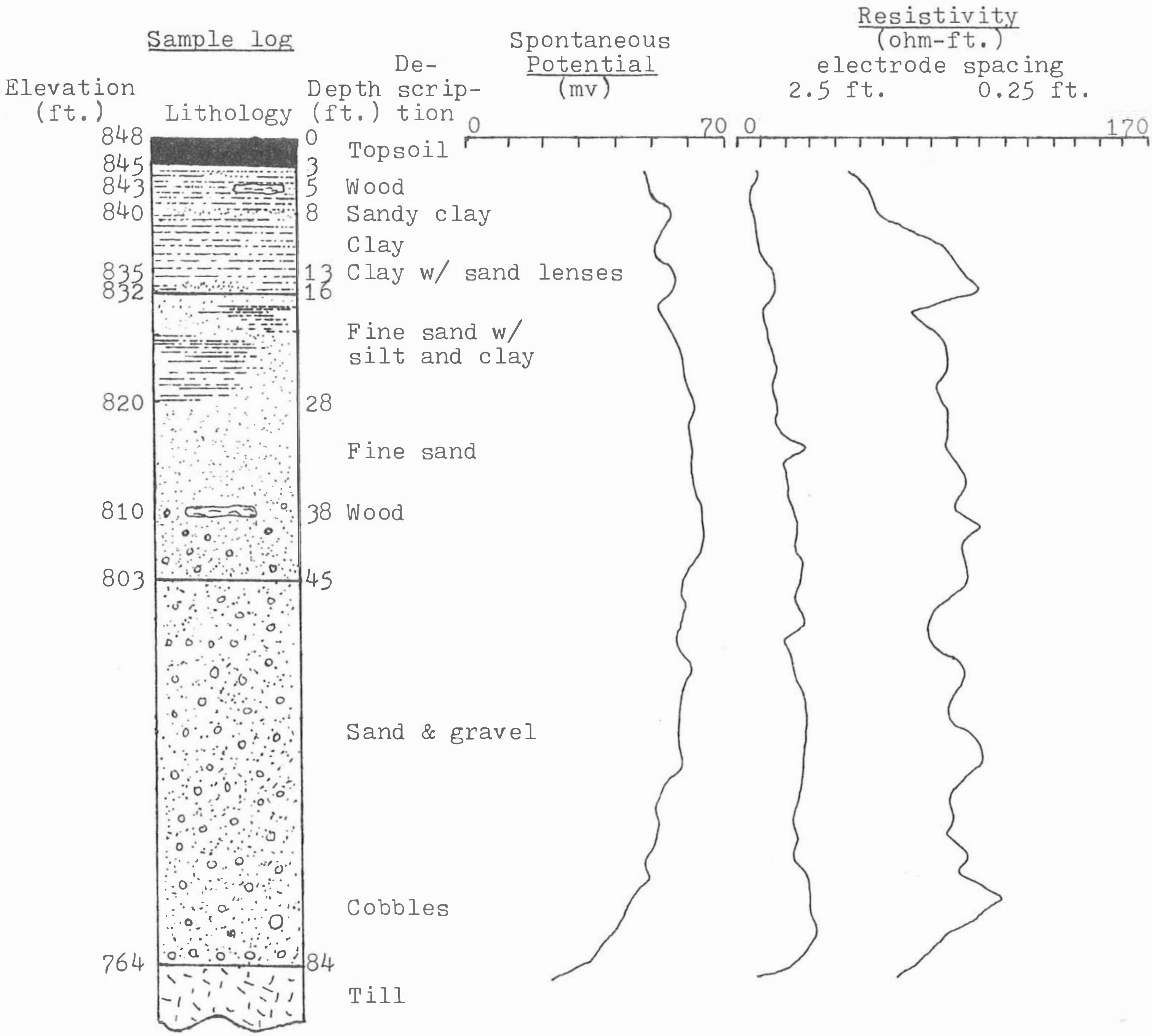

Vertical scale: 1" = 15'

# APPENDIX C

## Borehole Stratigraphic Data, Borehole OW-7

| Depth Below Surface, Feet From | To | Formation Description |
|---|---|---|
| 0 | 2.5 | Black topsoil |
| 2.5 | 3.5 | Muddy brown clay |
| 3.5 | 5 | Muddy brown sandy clay with wood at 5' |
| 5 | 13 | Brown clay |
| 13 | 15.5 | Blue gray clay with sand lenses |
| 15.5 | 18 | Blue gray sand and gravel - fine with thin streaks of clay |
| 18 | 20 | Sand and gravel - fine to medium - with no clay |
| 20 | 27.5 | Blue gray clay |
| 27.5 | 35 | Blue gray sand and gravel - fine to medium |
| 35 | 40 | Gray sand and gravel - medium - starting to clean - wood at 38' |
| 40 | 45 | Gray sand and gravel - medium in texture |
| 45 | 55 | Sand and gravel - clean (very) medium to coarse |
| 55 | 60 | Sand and gravel - pea rock size - coarse |
| 60 | 65 | Sand and gravel - coarse with trace of cobbles |
| 65 | 70 | Sand and gravel - very coarse with cobbles |
| 70 | 76 | Sand and gravel - very coarse with large cobbles |
| 76 | 84 | Very hard cemented sand and gravel with large cobbles and boulders. Drilled exactly like limestone except quicker going through streaks (thin simulated sandstone toward bottom) |
| 84 | 90 | Dark gray till |

OW-7 (SW/NE Section 21, T82N, R23W).




Vertical scale: 1" = 15'

# APPENDIX C

## Borehole Stratigraphic Data, City of Cambridge (Well log, Well 2, 1971)

| Depth Below Surface, Feet | | |
| --- | --- | --- |
| From | To | Formation Description |
| 0 | 3 | Black topsoil |
| 3 | 4 | Sandy brown clay |
| 4 | 10 | Brown sand |
| 10 | 25 | Sandy gray clay |
| 25 | 41 | Sandy gray clay - sand streaks |
| 41 | 54 | Gray sand |
| 54 | 60 | Gray sand - some gravel |
| 60 | 79 | Coarse gray sand and gravel |

## 9. ENGINEERING CERTIFICATION

I hereby certify that this report was prepared by me and under my personal supervision, and that I am a duly Registered Professional Engineer under the laws of the State of Iowa.

Merwin D. Dougal

Merwin D. Dougal, Ph.D., P.E.
Reg. No. 3985

September 30, 1980