# APPENDIX E

# HYDROGEOLOGIC EVALUATION OF ALTERNATIVES

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## 1.0 INTRODUCTION

Alternative groundwater remedial systems for the Site are evaluated in this appendix. The following three remedial response actions are evaluated:

- physical containment;
- hydraulic containment; and
- source removal.

This Appendix presents a description and evaluation of the different technologies associated with these response actions in order to select the optimum groundwater remedial alternative(s) to be retained for further evaluation in the FS.

The Site conceptualization, including a brief description of the geologic and hydrogeologic setting and the chemistry in the groundwater beneath the Site is presented in Section 2.0.

A brief discussion of the available groundwater remedial technologies used to develop the remedial alternatives is presented in Section 3.0.

The development and evaluation of the On Site Hydraulic Containment alternatives is provided in Section 4.0. The On Site Hydraulic Containment and Source Removal Alternatives are presented in Section 5.0.

## 2.0 SITE CONCEPTUALIZATION

A brief summary of the Site's physical characteristics is presented in this section. A more detailed assessment is presented in the RI Report.

### 2.1 SITE GEOLOGY

The two primary geologic units encountered during the RI, in descending order, are as follows:

1. Overburden:
   - topsoil,
   - fill,
   - silty sand and gravel; and
2. Bedrock:
   - weathered and fractured shale,
   - shale.

### 2.2 SITE HYDROGEOLOGY

Hydrogeologic characterization of the Site is difficult due to the irregular ground and bedrock topography, and the complex vertical and spatial distribution of varying native deposits and fill materials comprising the overburden. In general, however, three hydrostratigraphic units are defined for the Site.

A hydrostratigraphic unit is defined as a stratigraphic (geologic) unit which has similar hydraulic properties. Hydrostratigraphic units are designated aquifers (waterbearing zones) if they transmit groundwater or aquitards (confining) if they restrict groundwater flow.

The three hydrostratigraphic units, in descending order, are:

1. the Water Table Aquifer (Shallow Aquifer);
2. the Localized Overburden Aquitard Unit; and
3. the Bedrock Aquifer.

Shallow Aquifer

The Shallow Aquifer consists of the saturated portion of the more permeable, outwash sand and gravel deposits which constitute the bulk of the overburden. Also included in the Shallow Aquifer is the uppermost weathered interval (approximately one to three feet) of bedrock due to its highly weathered, fractured and permeable nature, and the direct hydraulic connection with the overlying granular deposits. The shale fill in the former lagoon areas is also included in this unit.

The Shallow Aquifer water table elevation contours using water level data from June 3, 2002, are provided on Figure E.1. The groundwater elevation contours in the Shallow Aquifer indicate a flow divide occurs in an east-west direction through the Site. Therefore, the groundwater flow in the Shallow Aquifer is divided into two flow components; north (north-northwest flow) and south (southwest-southeast flow).

The northern flow component is directed north-northwest of the Site. The average horizontal hydraulic gradient was calculated to be 0.0335. The hydraulic conductivity of the material comprising the Shallow Aquifer (upper fractured bedrock and overlying outwash sand and gravel deposits) was considered to be 2.8 ft/day. The average saturated thickness of the Shallow Aquifer was assumed to be five feet (two feet of fractured upper bedrock and three feet of overlying sand and gravel).

The southern flow component is directed southwest-southeast of the Site. The average horizontal hydraulic gradient was determined to be 0.021. The hydraulic conductivity of the material which comprises the Shallow Aquifer is 2.5 ft/day. The average saturated thickness of the Shallow Aquifer was assumed to be five feet as in the northern flow component.

Based on the Shallow Aquifer hydraulic parameters, the total groundwater flux (lateral flow) in the north and south components of the Site is 2.2 gpm (424 $ft^3$/day).

Due to the presence of the flow divide, it is considered that there is not a continuous through-flow system beneath the Site in the Shallow Aquifer. Therefore, the only groundwater which discharges to the south or north in the Shallow Aquifer originates as infiltration in the areas occupied by the southern and northern flow divides. In order to calculate the rate of groundwater discharge from the northern and southern flow components, the amount of infiltration for the area occupied by each flow component was estimated. As provided in the RI report, the Hydrological Evaluation of Landfill Performance (HELP) computer model was utilized to estimate the average annual infiltration at the Site. Based on an annual precipitation of approximately

39 inches/year, it was determined that the average annual infiltration for the Site is approximately 11 inches/year.

Using the above-noted infiltration rate and an area of 289,300 $ft^2$ (6.6 acres) for the northern flow component, the groundwater flux due to infiltration in this component was calculated to be approximately 3.5 gpm (674 $ft^3$/day). The groundwater flow due to infiltration in the southern flow component, based on an area of approximately 553,000 $ft^2$ (12.7 acres) and an infiltration rate of 11 inches/year, was calculated to be approximately 7.3 gpm (1,405 $ft^3$/day).

Overburden Aquitard Unit

The overburden aquitard unit is described as a localized, fine-grained deposits of silt and clay (till) within the overburden, predominantly occurring through the south end of the Site. Where present, this layer generally acts as an aquitard between the overlying sand deposits and the upper, fractured interval of bedrock. Groundwater may become perched on this layer or become confined in the underlying upper weathered bedrock interval.

Bedrock Aquifer

The Bedrock aquifer occurs as fracturing within the more competent portion of the shale bedrock. Fracturing may be frequent, although generally decreasing with depth.

The bedrock potentiometric contours using water level data from June 3, 23002 are presented on Figure E.2. The groundwater elevation contours in the Bedrock Aquifer also indicate a flow divide in an east-west direction. As well, the groundwater flow in the Bedrock Aquifer indicates two major flow components: north (north-northwest flow) and south (southwest flow) and a minor flow component in the west direction.

The northern flow component is directed north-northeast of the Site. The average horizontal hydraulic gradient was calculated to be 0.024. The hydraulic conductivity of the material comprising the Bedrock Aquifer was calculated to be 0.055 ft/day. However, the hydraulic conductivity estimated for the northern flow component differs with the southern flow component (0.54 ft/day) by one order of magnitude. As the hydraulic conductivity determined in the north flow component was based on only one in situ hydraulic test conducted on one bedrock monitoring well (MW-5D-95) during the RI and since the bedrock structure in the southern portion of the Site is similar to the northern portion of the Site, it is likely that the hydraulic conductivity in the northern component would be similar to the southern component. The hydraulic conductivity determined for the southern flow component was based on several in situ hydraulic tests (single-well response tests and short-duration pumping/recovery tests) on several southern bedrock monitoring wells. Therefore, as a conservative assumption, the hydraulic conductivity for the northern and southern flows are considered to be the same (0.54 ft/day). The average saturated thickness of the Bedrock Aquifer was assumed to be 120 feet.

The southern flow component is directed southwest of the Site. The average horizontal hydraulic gradient was calculated to be 0.023. The hydraulic conductivity of the material comprising the Bedrock Aquifer was considered to be 0.54 ft/day. The average saturated thickness of the Bedrock Aquifer was assumed to be 120 feet as in the northern flow component.

The total groundwater flux in the Bedrock Aquifer was calculated to be approximately 8 gpm (1,502 $ft^3$/day) based on the above-noted hydraulic parameters.

Hydraulic parameters for the Shallow and Bedrock Aquifers are summarized in Table E.1.

## 2.3 GROUNDWATER QUALITY

As indicated in Section 2.2.2 of the FS, the 2001 and 2002 groundwater data collected by CRA is considered to be the most representative of the current water quality data at the Site. A summary of the groundwater analytical data is presented in Table 2.3 of the FS. A complete discussion of the analytical results is presented in the RI Report.

## 3.0 GROUNDWATER CONTAINMENT/EXTRACTION REMEDIAL TECHNOLOGIES

A brief description of the available technologies which may be used to develop potential groundwater containment and/or extraction alternatives is presented in this section.

### 3.1 BARRIER WALL

This technology involves the construction of a low permeability barrier that impedes groundwater flow. A barrier wall is usually constructed by excavating a trench (under a slurry) and mixing the native soil with local clay, soil-bentonite, or cement-soil-bentonite to form the trench backfill. Upon completion, the barrier wall has a much lower permeability than the surrounding soil which provides protection against contaminant migration.

The barrier wall may be located downgradient of a groundwater extraction system to reduce the volume of water drawn back from the downgradient side. Also, the wall may be used to physically contain contaminants in a source area if it can be "keyed" into a low permeability underlying unit. Alternatively, a barrier wall may be located at the upgradient side of a contaminated area to reduce the groundwater flux and the groundwater extraction rate required for hydraulic containment downgradient of the barrier wall.

### 3.2 GROUNDWATER EXTRACTION WELLS

This technology utilizes a series of groundwater extraction wells (normally ranging between 4 and 8 inches in diameter) equipped with pumps to extract groundwater. The collected water would subsequently be treated and disposed on or off Site. Pumping of an extraction well provides hydraulic containment of groundwater in a zone around the well. The limits of the capture zone associated with an extraction well would be a function of the pumping rate and the hydraulic properties of the aquifer (i.e., transmissivity and horizontal hydraulic gradient). Extraction wells are best suited to withdrawing groundwater from relatively transmissive units (aquifers).

## 3.3 TILE COLLECTION SYSTEM

This technology involves the construction of a tile collection system which would intercept contaminated groundwater. Water collected by the tile system would be treated prior to discharge. Construction of the tile system would involve excavation of a trench. A perforated HDPE pipe would then be installed in the bottom of the trench. The pipe would then be sloped to a "wet well" or pumping station from which the collected water would be extracted. The trench would then be backfilled with granular material to the top of the water table to provide a preferential pathway for the groundwater. This technology is only suitable for collection of overburden groundwater at relatively shallow depths (approximately 20 feet).

## 4.0 GROUNDWATER HYDRAULIC CONTAINMENT ALTERNATIVES

The objective of on Site hydraulic containment is to minimize the potential for migration of the chemicals off Site through contaminant transport in groundwater. The following alternatives consider hydraulic containment in the Shallow Aquifer (overburden and upper fractured and weathered bedrock) and in the Bedrock Aquifer. Certain alternatives include the construction of a barrier wall in the overburden for the shallow groundwater.

The following subsections provide a hydrogeologic evaluation of the following hydraulic containment alternatives:

| | |
|---|---|
| Alternative 1A | Shallow Aquifer Extraction Wells<br>Bedrock Aquifer Extraction Wells |
| Alternative 1B | Shallow Aquifer Extraction Wells<br>Bedrock Aquifer Extraction Wells<br>Overburden Barrier Walls |
| Alternative 1C | Shallow Aquifer Tile Collection System<br>Bedrock Aquifer Extraction Wells |
| Alternative 1D | Bedrock Aquifer Extraction Wells<br>Shallow Aquifer Tile Collection System<br>Overburden Barrier Wall |
| Alternative 2 | Bedrock Aquifer Extraction Wells<br>Shallow Aquifer Tile Collection System<br>Source Extraction. |

### 4.1 ALTERNATIVE 1A - SHALLOW AQUIFER EXTRACTION WELLS AND BEDROCK AQUIFER EXTRACTION WELLS

This alternative would involve the installation of a number of groundwater extraction wells at the downgradient limits of the Site in both the Shallow and Bedrock Aquifers. Pumping from these wells would provide hydraulic containment of groundwater in both the Shallow and Bedrock Aquifers.

Each of the Bedrock Aquifer extraction wells would be approximately six inches in diameter and completed in the bedrock to intercept a series of water-bearing fractures down to a maximum depth of approximately 120 feet below ground surface (bgs). Each extraction well would include a maximum of 50 feet of open hole in the Bedrock Aquifer.

Each of the Shallow Aquifer extraction wells would be approximately four inches in diameter and completed at the top of competent bedrock to screen the sand and gravel material and the upper two feet of fractured bedrock. Although the stratigraphy is variable beneath the Site, the average depth of the water table extraction wells would be approximately 20 feet bgs.

The total groundwater flux in the Bedrock Aquifer was determined to be approximately 8 gpm (1,540 $ft^3$/day). To provide hydraulic containment of the groundwater in the Bedrock Aquifer, the total extraction rate for the bedrock extraction wells would have to be equivalent to a minimum of twice the groundwater flux or 16 gpm (3,080 $ft^3$/day).

The optimum placement of the groundwater extraction wells is a function of the following hydraulic parameters:

- hydraulic conductivity of the aquifer materials;
- saturated thickness of the aquifer; and
- horizontal hydraulic gradient of the aquifer.

As discussed in Section 2.2, the transmissivity of the Bedrock Aquifer in both the northern and southern flow was considered to be 67 $ft^2$/day, corresponding approximately to a hydraulic conductivity of approximately 0.54 ft/day and a saturated thickness of approximately 120 feet (transmissivity equals the product of hydraulic conductivity and saturated aquifer thickness). The horizontal hydraulic gradient in the northern and southern flow were estimated as 0.024 and 0.023, respectively.

An initial pumping rate of 3.5 gpm (674 $ft^3$/day) was estimated for each Bedrock Aquifer extraction well (total extraction rate of 17.5 gpm). Based on the above-noted pumping rate, the capture zone for each extraction well was calculated by the following equation (Todd, 1980):

$$r_c = \frac{Q}{2\pi Ti}$$

where:

| | | |
|---|---|---|
| $r_c$ | = | distance from the extraction well to the downgradient stagnation point (ft) |
| Q | = | pumping rate ($ft^3$/day) |
| T | = | aquifer transmissivity ($ft^2$/day) |
| | = | hydraulic conductivity (ft/day) x saturated aquifer thickness (ft) |
| i | = | horizontal hydraulic gradient (ft/ft) |
| $\pi rc$ | = | maximum width of the capture zone at each extraction well (ft) |

The results of the capture zone for a pumping rate of 3.5 gpm in the northern and southern portions of the Site were as follows:

| | | *North (ft)* | *South (ft)* |
|---|---|---|---|
| a) | distance to the downgradient stagnation point ($r_c$) | 69 | 72 |
| b) | maximum width of capture zone at the extraction well ($\pi r_c$) | 216 | 225 |

Based on the pumping rate of 3.5 gpm (674 $ft^3$/day) per Bedrock Aquifer extraction well (total of five extraction wells) the groundwater in the bedrock would not be hydraulically contained at the Site boundaries.

In order to hydraulically contain the groundwater in the bedrock using five bedrock extraction wells, the pumping rate for each extraction well will be 9 gpm (1,733 $ft^3$/day). The results of the capture zone for a pumping rate of 9 gpm in the northern and southern portions of the Site were as follows:

| | | *North (ft)* | *South (ft)* |
|---|---|---|---|
| a) | distance to the downgradient stagnation point ($r_c$) | 177 | 184 |
| b) | maximum width of capture zone at the extraction well ($\pi r_c$) | 555 | 579 |

The groundwater extraction well layout utilizing a pumping rate of 9 gpm (1,732 $ft^3$/day) per bedrock extraction well is presented on Figure E.3.

The results of the capture zone calculations are provided in Table E.2 (an example calculation is provided in Attachment I of this Appendix).

The groundwater flows due to precipitation infiltration in the northern and southern flow components of the Shallow Aquifer were determined to be approximately 3.5 gpm (674 $ft^3$/day)and 7.3 gpm (1,405 $ft^3$/day), respectively (see Section 2.2). In order to provide hydraulic containment along the downgradient Site boundaries in the northern and southern flow components, the total discharge rate for the Shallow Aquifer extraction wells in the northern and southern boundaries would have to be equivalent to approximately twice the groundwater fluxes in these components or 7 gpm (1,348 $ft^3$/day) and 15 gpm (2,888 $ft^3$/day), respectively.

As previously indicated, the optimum placement of the groundwater extraction wells is a function of the hydraulic conductivity of the aquifer material, the saturated thickness and the horizontal hydraulic gradient of the aquifer.

Due to the limited saturated thickness (5 feet) of the Shallow Aquifer, a pumping rate of 0.5 gpm (96.3 $ft^3$/day) was estimated for each water table extraction well to produce drawdowns of less than five feet. Based on the hydraulic parameters for the Shallow Aquifer (Section 2.2) and pumping rate of 0.5 gpm (96.3 $ft^3$/day), the capture zone for each water table extraction well was calculated by the Todd (1980) equation.

The results of the capture zone calculations are provided in Table E.2 and an example calculation is provided in Attachment I to this Appendix. The results of the capture zone for a pumping rate of 0.5 gpm (96.3 $ft^3$/day) in the northern and southern portions of the Site were as follows:

| | | ***North (ft)*** | ***South (ft)*** |
|---|---|---|---|
| a) | distance to the downgradient stagnation point ($r_c$) | 33 | 58 |
| b) | maximum width of capture zone at the extraction well ($\pi r_c$) | 103 | 183 |

In order to provide hydraulic containment in the northern flow component, the total discharge rate would have to be equal to twice the groundwater flux due to infiltration or 7 gpm (1,348 $ft^3$/day). Thus pumping at a rate of 0.5 gpm (96.3 $ft^3$/day) per extraction well, 14 Shallow Aquifer extraction wells would be required along the downgradient Site limit of the northern flow component. The Shallow Aquifer extraction well layout is provided on Figure E.3. To provide hydraulic containment in the southern flow component, the total discharge rate would have to be equal to twice the groundwater flux due to precipitation infiltration or 15 gpm (2,888 $ft^3$/day). Therefore, pumping at a rate of 0.5 gpm (96.3 $ft^3$/day) per extraction well, 30 Shallow Aquifer extraction wells would be needed along the downgradient Site limit of the southern flow component, as presented on Figure E.3. The total withdrawal rate for the extraction wells in the Shallow Aquifer would be approximately 22 gpm (4,235 $ft^3$/day).

Therefore, the total withdrawal rate for Alternative 1A would be approximately 67 gpm (12,898 $ft^3$/day).

Due to the number of Shallow Aquifer extraction wells (total of 44 wells) Alternate 1A was not considered to be a cost effective hydraulic containment alternative. Therefore, this alternative was not further developed.

## 4.2 ALTERNATIVE 1B - SHALLOW AQUIFER EXTRACTION WELLS, BEDROCK AQUIFER EXTRACTION WELLS AND OVERBURDEN BARRIER WALL

The groundwater extraction well and barrier wall technologies have been combined to form this alternative. To provide hydraulic containment in the Bedrock Aquifer, groundwater extraction wells would be installed at the downgradient limits of the Site. Pumping from these wells would provide hydraulic containment of groundwater in the Bedrock Aquifer. In order to provide hydraulic containment in the Shallow Aquifer, a barrier wall would be installed using the downgradient Site boundaries of the northern and southern flow components. This alternative is schematically presented on Figure E.4.

If a barrier wall alone were installed downgradient of the northern and southern flow components, water levels inside the wall would build and leakage would increase with time, diminishing its effectiveness, unless groundwater extraction is also included. Thus, for the Shallow Aquifer, a barrier wall would be installed and groundwater extraction wells would be placed upgradient and adjacent to the barrier wall.

As discussed in Section 4.1, to hydraulically contain groundwater in the Bedrock aquifer, it would be necessary to install five extraction wells pumping at a rate of 9 gpm (1,733 $ft^3$/day) (per extraction well). The bedrock groundwater extraction well layout for this alternative is shown on Figure E.4. The total withdrawal rate for the extraction wells in the Bedrock Aquifer would be approximately 45 gpm (8,663 $ft^3$/day).

Hydraulic containment in the Shallow Aquifer includes a barrier wall alignment at the downgradient Site boundary in the northern and southern flow components. The length of the barrier wall at the downgradient Site boundaries in the northern and southern flow components would be approximately 580 feet and 1020 feet, respectively. The northern and southern barrier wall alignments are shown on Figure E.4.

The design criteria for the barrier wall would be the following:

- the barrier wall would be a minimum of 3 feet wide;
- the barrier wall would extend a minimum of 2 feet below the upper fractured bedrock into competent bedrock; and
- the materials which would comprise the barrier wall would have a hydraulic conductivity equal or less than $1.0 \times 10^{-7}$ cm/sec.

This alternative also involves the installation of extraction wells in the Shallow Aquifer. These wells would extract groundwater to prevent flow through the barrier wall.

For the barrier wall to be effective, an inward hydraulic gradient would have to be created across the barrier wall. This inward hydraulic gradient would indicate that groundwater flow north along the northern flow component and south along the southern flow component would be intercepted by the groundwater extraction wells.

Due to presence of the barrier wall along the downgradient Site boundaries in the northern and southern flow components, the total discharge rates for the extraction wells in the northern and southern barrier wall alignments would have to be equal to the groundwater flows due to the infiltration. Thus, the total discharge rates for the Shallow Aquifer extraction wells that would be installed upgradient of the northern and southern flow components would be 3.5 gpm (674 $ft^3$/day) and 7.3 gpm (1,405 $ft^3$/day), respectively.

Based on a pumping rate of 0.5 gpm (96.3 $ft^3$/day) (per groundwater extraction well), seven (7) and fifteen (15) extraction wells would be installed upgradient and adjacent to the northern and southern barrier wall alignments, respectively.

It is estimated that the total withdrawal rate for Alternative 1B would be approximately 56 gpm (10,780 $ft^3$/day).

The barrier wall would be over 1,500 feet long (600 feet in the north and 1,000 feet in the south) and therefore expensive to construct. The effectiveness of a barrier wall may be compromised if an inward hydraulic gradient is not maintained across the Site. Over time, the integrity of the barrier wall may deteriorate due to hydraulic differential across the wall. Therefore, this alternative was not further developed.

## 4.3 ALTERNATIVE 1C - BEDROCK AQUIFER EXTRACTION WELLS AND SHALLOW AQUIFER TILE COLLECTION SYSTEM

This remedial alternative would involve the installation of bedrock groundwater extraction wells to hydraulically contain groundwater in the Bedrock aquifer at the downgradient Site boundaries. In addition, this alternative would include tile collection systems installed at the downgradient Site boundaries in the northern and southern flow components of the Shallow Aquifer.

Pumping of the Bedrock Aquifer extraction wells would provide hydraulic containment of groundwater in the Bedrock Aquifer.

The tile collection system would intercept groundwater flowing from the flow divide in the Shallow Aquifer to the south and north, thereby, providing hydraulic containment as shown on Figure E.5.

The tile collection system would consist of 6-inch diameter perforated pipe with a filter stone bedding installed to a depth corresponding to the base of the upper two feet of weathered and fractured bedrock (base of the Shallow Aquifer).

As discussed in the previous section, to hydraulically contain groundwater in the Bedrock Aquifer, it would be necessary to install five extraction wells pumping at a rate of 9 gpm (1,733 $ft^3$/day) per extraction well. The layout for the bedrock groundwater extraction wells for this alternative is presented on Figure E.5. It is estimated that the total withdrawal rate for the extraction wells in the Bedrock Aquifer would be approximately 45 gpm (8,663 $ft^3$/day).

To provide effective hydraulic containment in the Shallow Aquifer, the tile collection system must collect the groundwater flow due to infiltration. As discussed in Section 2.2, the infiltration in the areas occupied by the northern and southern flow components are 3.5 gpm (674 $ft^3$/day) and 7.3 gpm (1,405 $ft^3$/day), respectively. However, the tile collection system would collect the groundwater from the northern and southern flow components as well as the areas downgradient at these components.

It is estimated that the tile collection system would collect twice the infiltration flow rates to capture flow upgradient and downgradient, at a rate of 7 gpm (1,348 $ft^3$/day) from the southern flow component and 15 gpm (2,888 $ft^3$/day) from the northern flow component.

It should be noted that due to the limited saturated thickness in the Shallow Aquifer (approximately 5 feet), a tile collection system is preferred to hydraulically contain groundwater in the Shallow Aquifer (in comparison to extraction wells).

The total withdrawal rate for Alternative 1C is estimated to be approximately 67 gpm (12,898 $ft^3$/day).

It is considered that Alternative 1C would provide an effective method for hydraulic containment of groundwater and is also a more cost effective option than Alternative 1A and 1B.

## 4.4 ALTERNATIVE 1D - BEDROCK AQUIFER EXTRACTION WELLS, SHALLOW AQUIFER TILE COLLECTION SYSTEM AND OVERBURDEN BARRIER WALL

This remedial alternative consists of groundwater extraction wells in the Bedrock Aquifer to hydraulically contain groundwater in this aquifer at the downgradient Site boundaries. This alternative also involves the installation of a tile collection system upgradient and adjacent to a barrier wall to intercept and collect groundwater in the Shallow Aquifer as shown on Figure E.6.

Pumping of the bedrock groundwater extraction wells would provide hydraulic containment of groundwater in the Bedrock Aquifer. As indicated in the previous sections, to hydraulically contain groundwater in the Bedrock aquifer, it would be necessary to install five extraction wells pumping at a rate of 9 gpm (1,733 $ft^3$/day) (per extraction well). The bedrock groundwater extraction wells would be placed along the downgradient Site boundaries as presented on Figure E.6. It is expected that the total withdrawal rate for the extraction wells in the Bedrock Aquifer would be approximately 45 gpm (8,663 $ft^3$/day).

The tile collection system would provide an inward hydraulic gradient in the upgradient side of the barrier wall, to provide effective collection of groundwater at the downgradient Site limits of the northern and southern flow components in the Shallow aquifer. It is estimated that for the northern flow component, the flow rate associated with the tile collection system would be approximately 3.5 gpm (674 $ft^3$/day) from precipitation infiltration. Due to the presence of the barrier wall adjacent to the tile collection system, groundwater flow would not be collected from the upgradient side of the collection system. It is estimated that for the southern flow component, the flow associated with the tile collection system would be approximately 7.3 gpm (1,405 $ft^3$/day) from infiltration. The total withdrawal rate from the Shallow Aquifer would be expected to be approximately 11 gpm (2,118 $ft^3$/day).

The total withdrawal rate for Alternative 1D is estimated to be approximately 56 gpm (10,780 $ft^3$/day).

The decrease in the groundwater extraction rate provided by the barrier wall relative to the tile collection system is estimated to be approximately 11 gpm.

Due to the relatively thin saturated zone, low chemical concentrations and low chemical mass flux via the Shallow Aquifer, the added benefit of a barrier wall in this application is considered to be minimal. Therefore this alternative was not further developed.

## 4.5 ALTERNATIVE 2 - BEDROCK AQUIFER EXTRACTION WELLS, TILE COLLECTION SYSTEM, AND SOURCE REMOVAL EXTRACTION WELLS

As discussed in Section 4.3, the preferred groundwater containment alternative involves the construction of a north and south component tile collection system as well as five bedrock extraction wells (see Figure E.5). This downgradient groundwater containment system could be optimized with the addition of source removal extraction wells located in the center of the highest levels of contamination (i.e., in proximity to the former lagoons).

Both groundwater containment and on Site source removal technologies have been combined to form a hybrid alternative. The objective of this alternative is to minimize the potential for off Site migration of the chemicals in the groundwater beneath the Site. This alternative involves hydraulic containment in the Shallow Aquifer and in the Bedrock Aquifer as well as groundwater extraction in areas of significant groundwater concentrations. This hybrid alternative should serve to accelerate aquifer restoration.

This remedial alternative involves the installation of bedrock extraction wells to hydraulically contain groundwater in the Bedrock Aquifer and to provide mass removal in the area of highest chemical presence detected in the Bedrock Aquifer. It is considered that six bedrock groundwater extraction wells pumping at a rate of 9 gpm (1,733 $ft^3$/day) would be required for a total withdrawal rate of 54 gpm (10,395 $ft^3$/day) (see Figure E.7).

The components of the Shallow Aquifer extraction system would be a tile collection system installed along the downgradient Site boundaries in the northern and southern flow components to hydraulically contain the groundwater in the Shallow Aquifer. The alignments of the tile collection systems are presented on Figure E.7. In addition, two mass removal Shallow Aquifer extraction wells would be placed in the vicinity of the highest chemical presence detected in the Shallow Aquifer. The total withdrawal rate for the Shallow Aquifer would be approximately 23 gpm (4,428 $ft^3$/day).

The total withdrawal rate for Alternative 2 would be approximately 79 gpm (15,208 $ft^3$/day).

The shallow groundwater extraction rate (23 gpm) is 1 gpm greater than the shallow groundwater extraction rate (22 gpm) required for groundwater containment alone (Alternative 1A). Due to the very limited saturated thickness on the Shallow Aquifer in the source area, the actual chemical mass that would be extracted from the groundwater source area would be relatively small, hence the added benefit of source removal relative to groundwater containment is considered to be minimal. Therefore, this alternative was not further developed.

## 5.0 SUMMARY

Based upon the evaluation of alternatives presented in the previous sections, it is concluded that the optimal groundwater remediation alternative includes installation of a tile collection system for the Shallow Aquifer combined with extraction wells for the Bedrock Aquifer (Alternative 1C). This option will be utilized in the FS report for all alternatives which include groundwater extraction.

Due to the relatively shallow (<20 feet) depth to bedrock and the thin saturated overburden thickness, the tile drain collector would be more cost effective than Shallow Aquifer extraction wells. A large number of Shallow Aquifer extraction wells would have to be installed and maintained to provide similar containment in comparison to the tile collection system. Also, the addition of a barrier wall offers minimal benefits and carries high construction costs. Therefore, neither of these technologies are recommended in the final, proposed groundwater remediation plan (Alternatives 1A, 1B, 1D, and 2).

The tile collection system would be completed to draw from the Shallow Aquifer. The Bedrock Aquifer extraction wells would be completed such that they draw water from all permeable strata through the entire bedrock section. The wells should be thoroughly developed and individually tested for yield. The final design of a groundwater extraction system would be subject to field testing of individual wells (and the performance of the system as a whole). Pumping rates may be individually adjusted to provide the optimal, composite capture zone pattern. Also, due to the areal variability of the bedrock aquifer characteristics, the proposed system of extraction wells may be further refined based on the geologic conditions encountered and test pumping results.

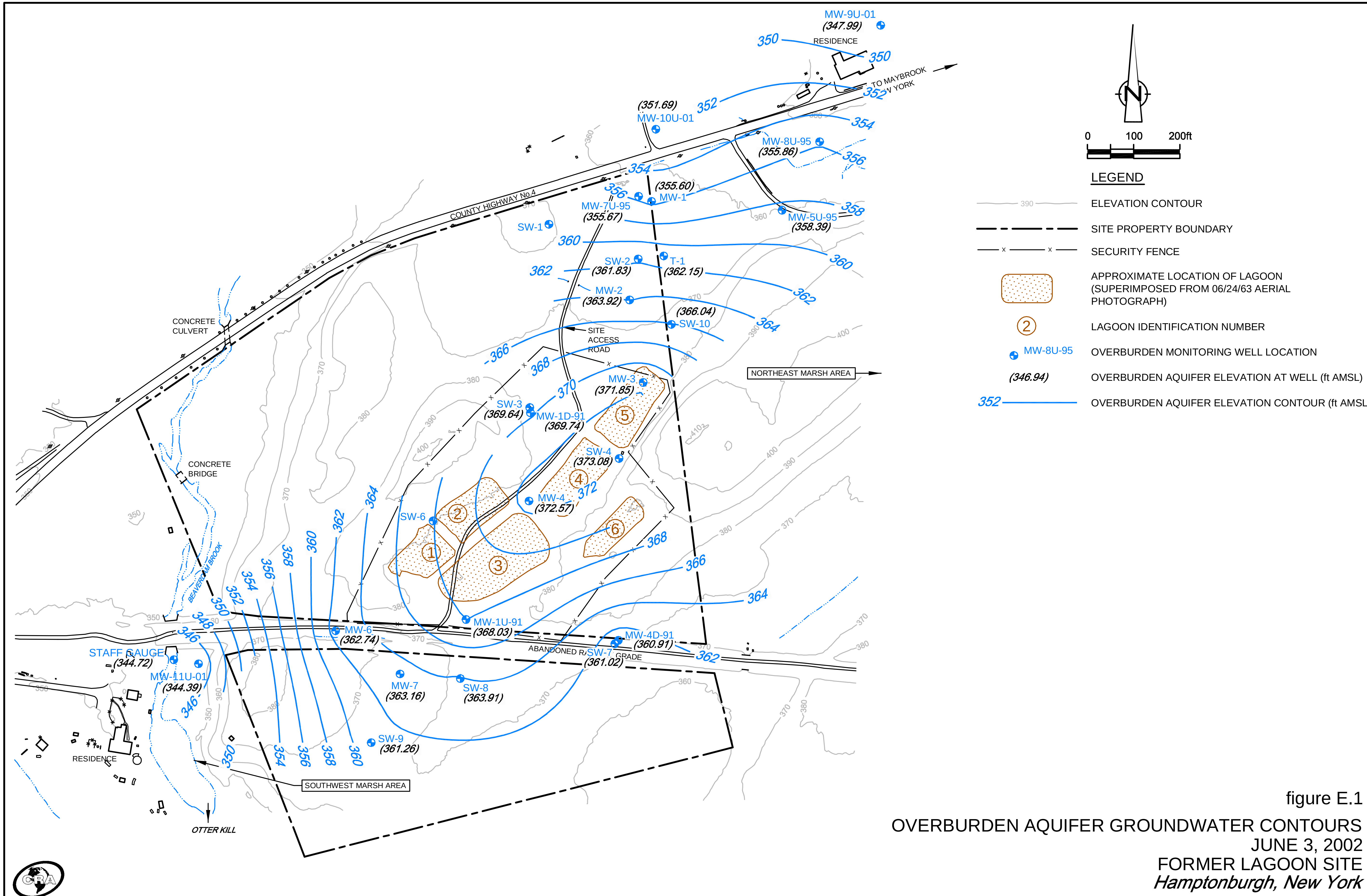


figure E.1

OVERBURDEN AQUIFER GROUNDWATER CONTOURS
JUNE 3, 2002
FORMER LAGOON SITE
*Hamptonburgh, New York*

03698-00(032)GN-WA006 JUN 23/2006

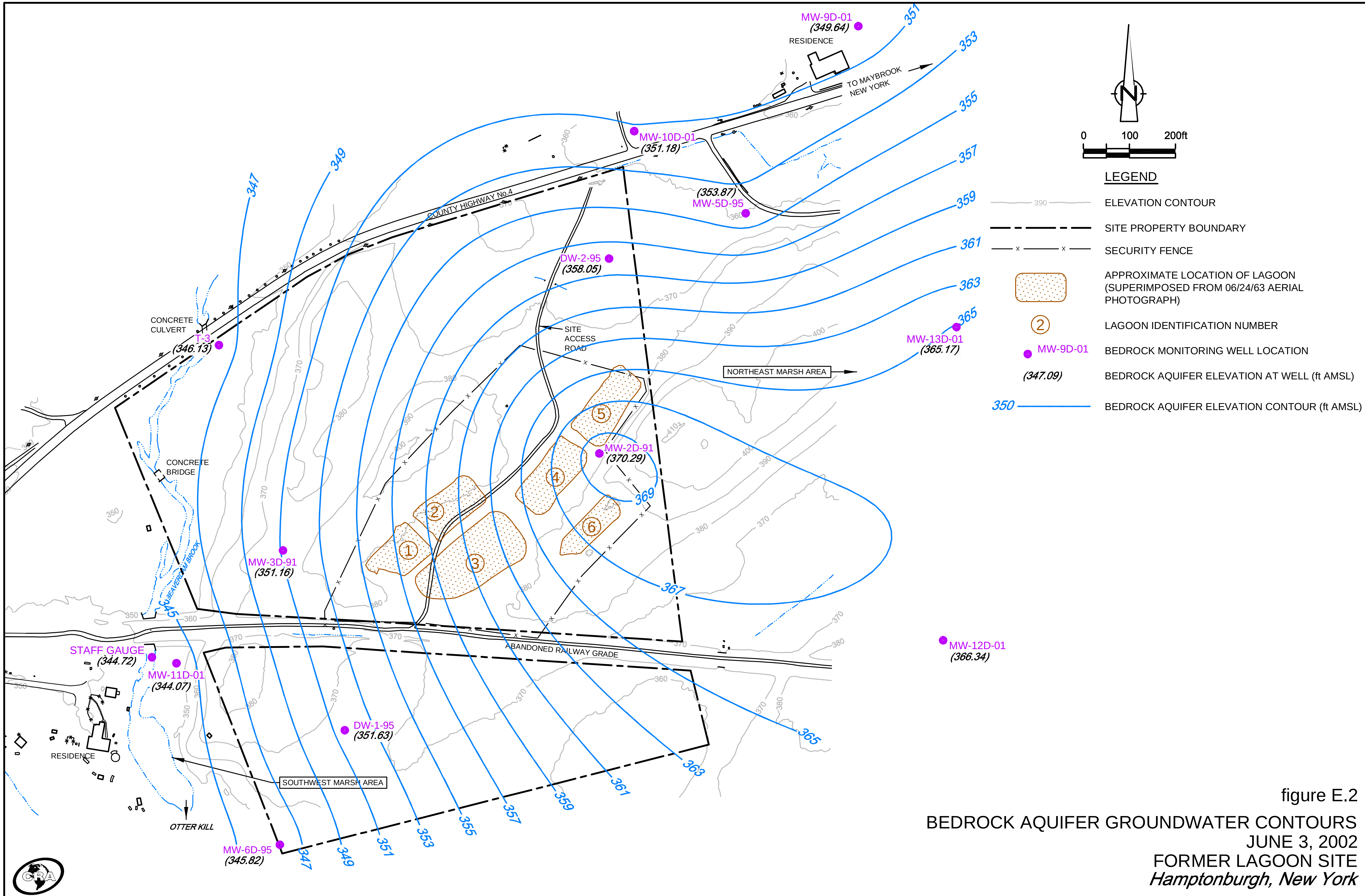


figure E.2

BEDROCK AQUIFER GROUNDWATER CONTOURS
JUNE 3, 2002
FORMER LAGOON SITE
*Hamptonburgh, New York*

03698-00(032)GN-WA007 JUN 23/2006

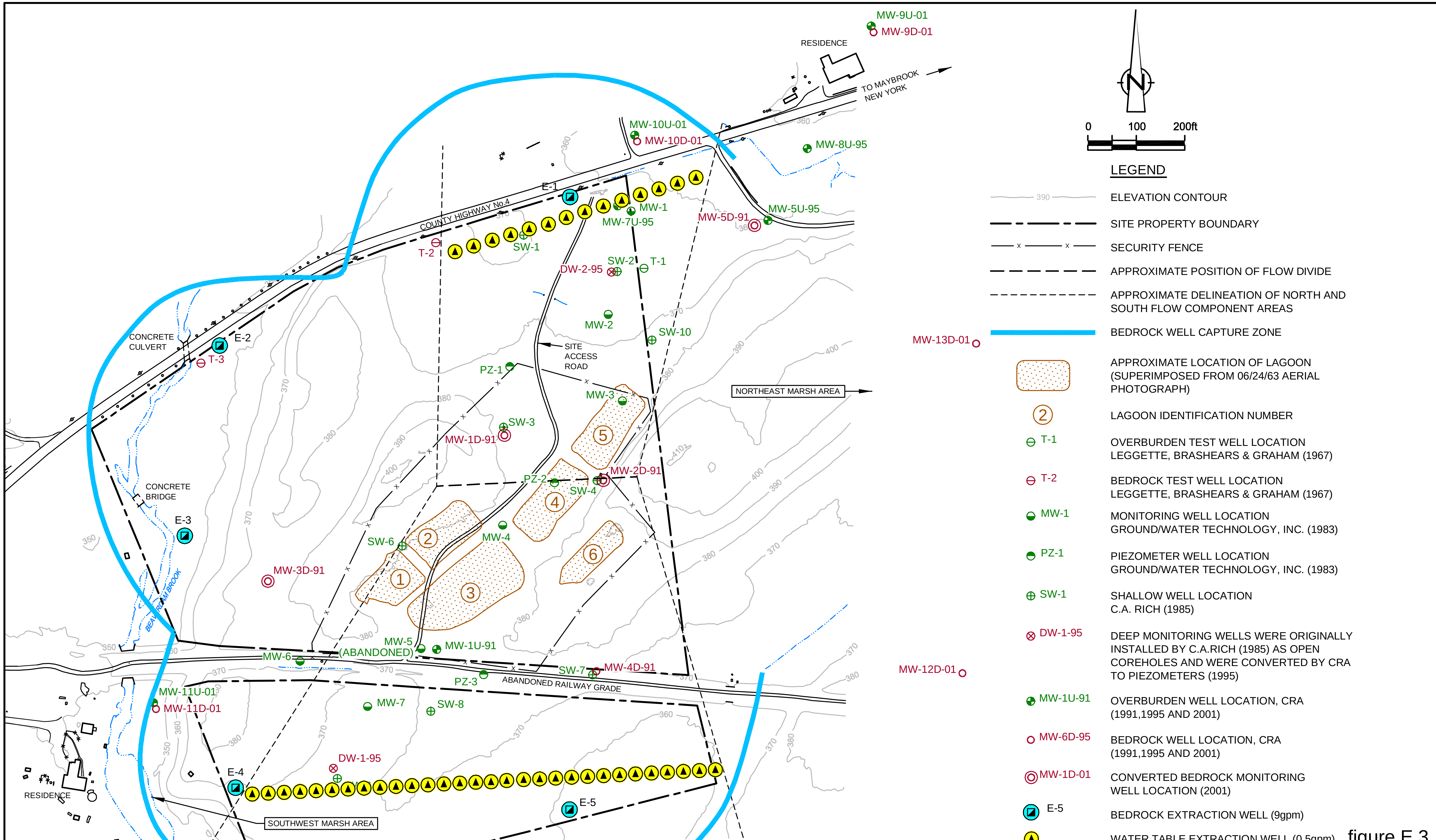


figure E.3

ALTERNATIVE 1A - ON-SITE HYDRAULIC CONTAINMENT (BEDROCK AND SHALLOW AQUIFER EXTRACTION WELLS)
FORMER LAGOON SITE
*Hamptonburgh, New York*

03698-00(032)GN-WA009 AUG 01/2006

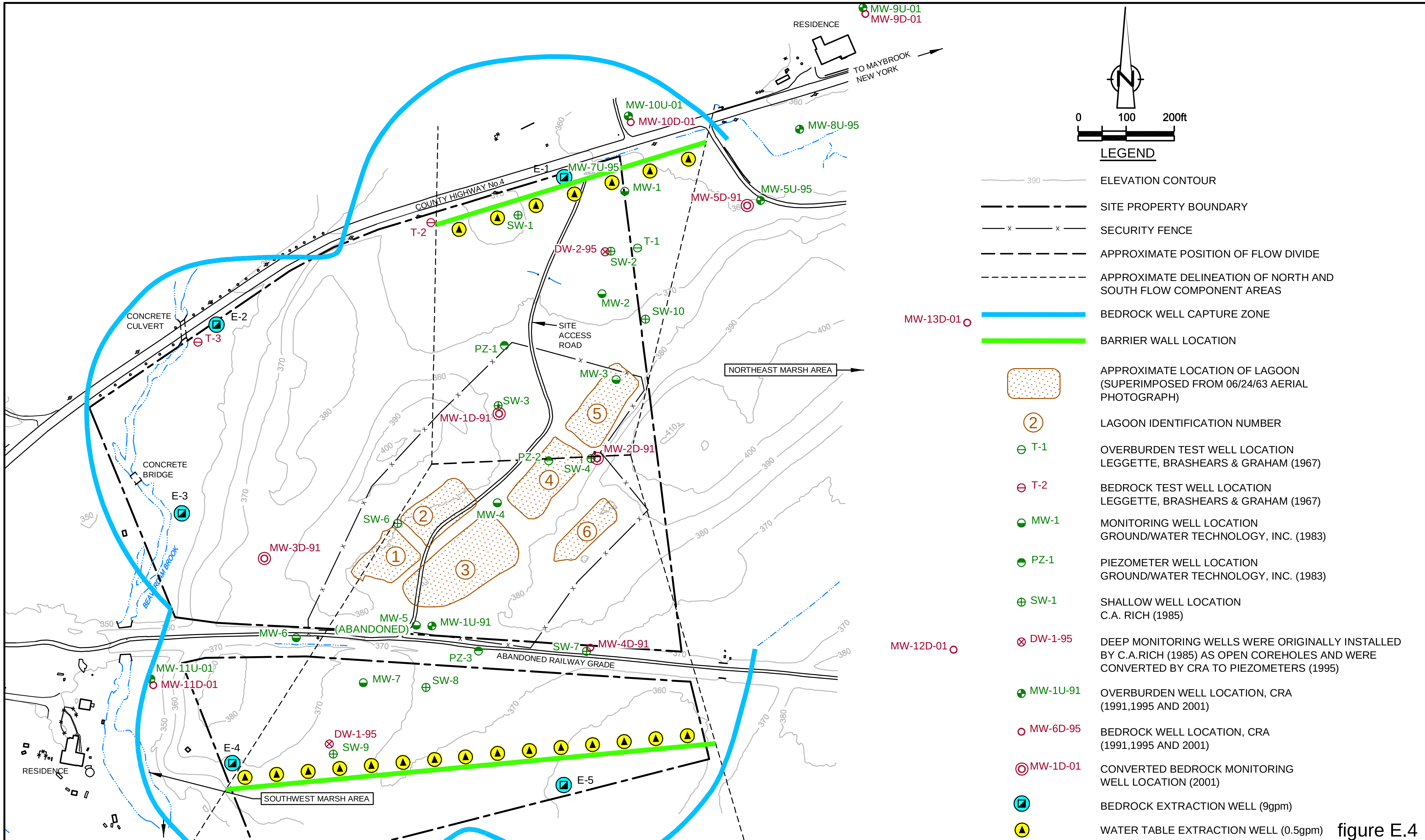


figure E.4

ALTERNATIVE 1B - ON-SITE HYDRAULIC CONTAINMENT
(BEDROCK AQUIFER EXTRACTION WELLS, SHALLOW AQUIFER EXTRACTION WELLS AND BARRIER WALL)
FORMER LAGOON SITE
*Hamptonburgh, New York*

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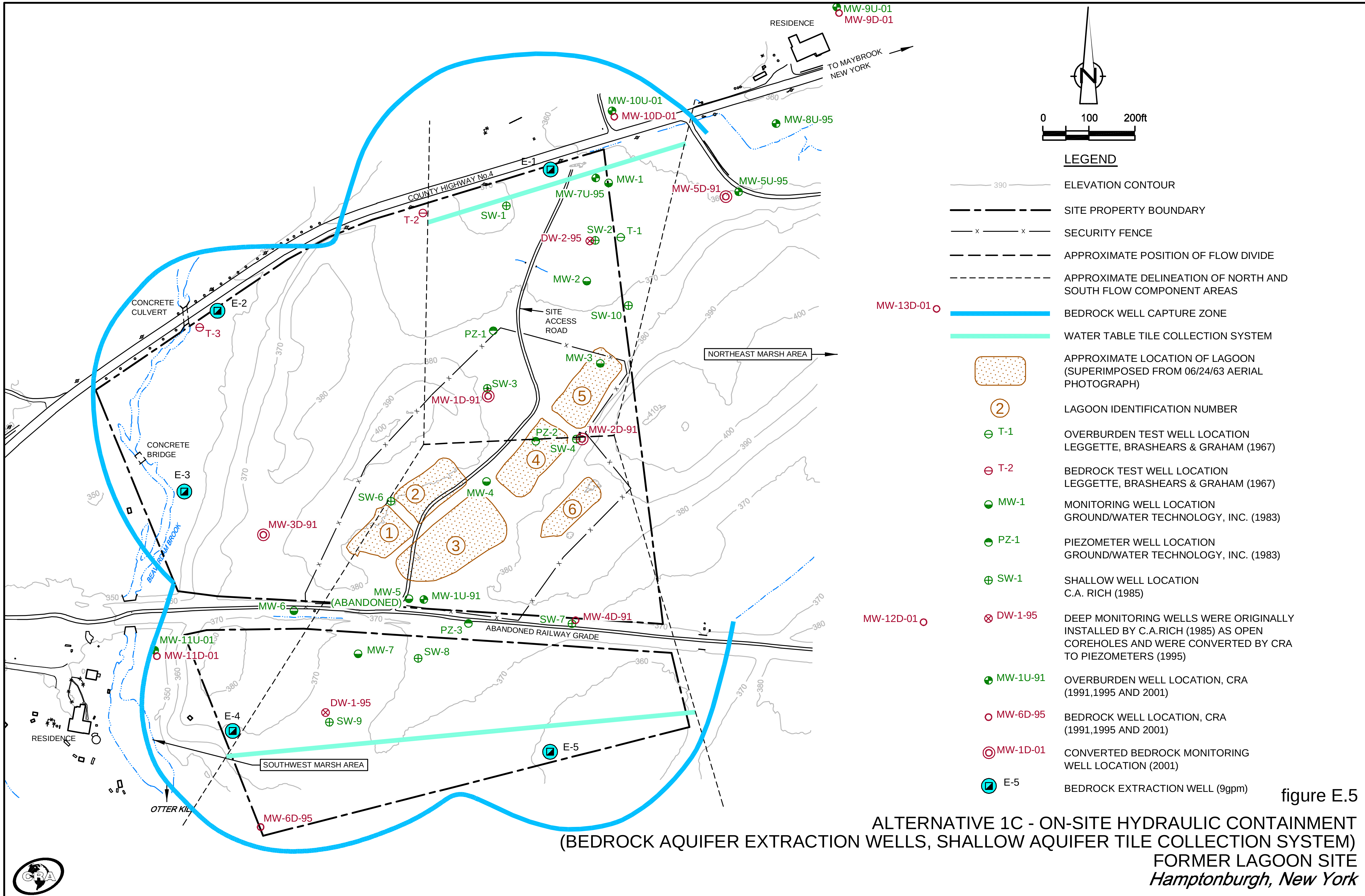


figure E.5

ALTERNATIVE 1C - ON-SITE HYDRAULIC CONTAINMENT
(BEDROCK AQUIFER EXTRACTION WELLS, SHALLOW AQUIFER TILE COLLECTION SYSTEM)
FORMER LAGOON SITE
*Hamptonburgh, New York*

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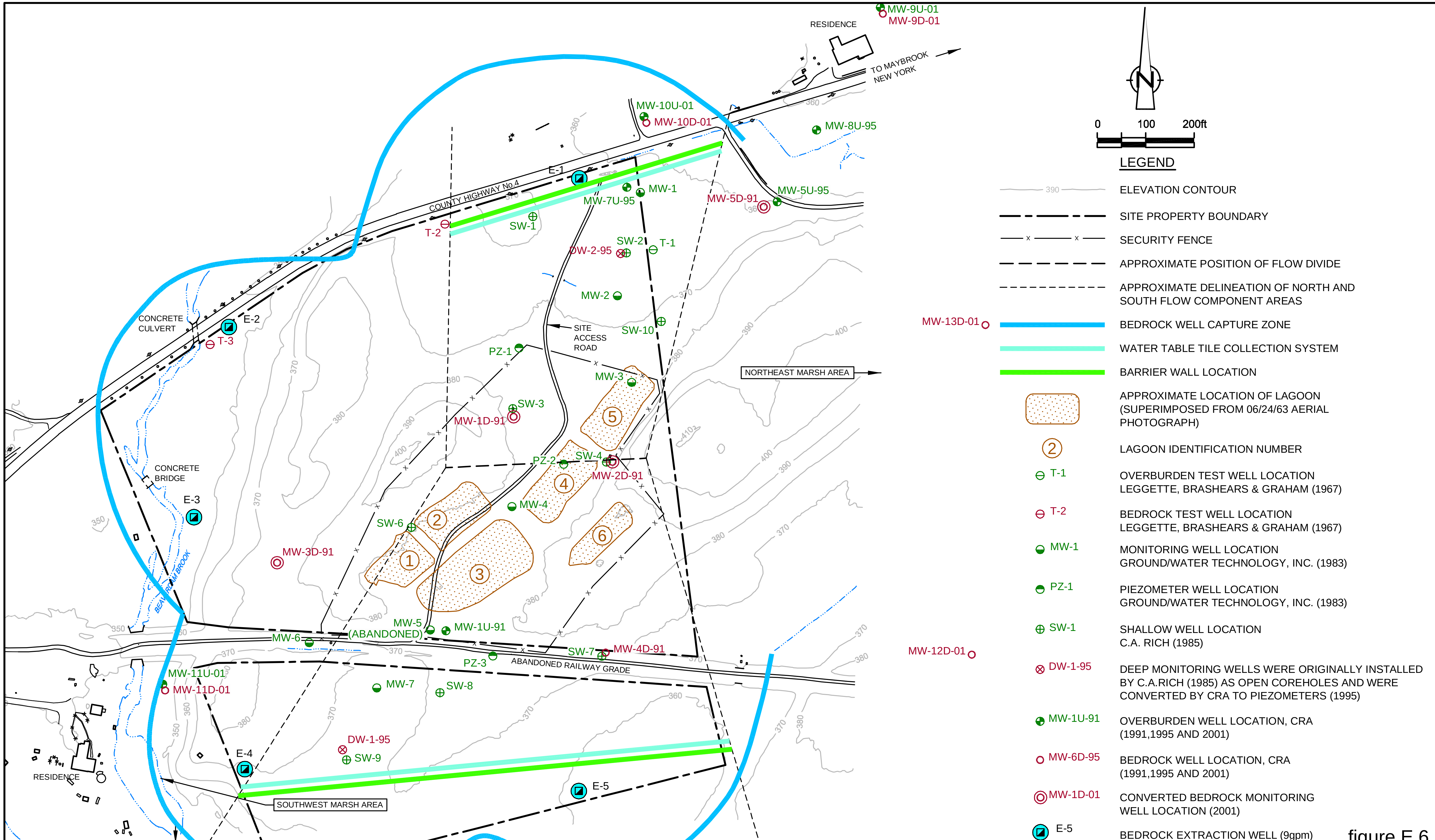


figure E.6

ALTERNATIVE 1D - ON-SITE HYDRAULIC CONTAINMENT
(BEDROCK AQUIFER EXTRACTION WELLS, SHALLOW AQUIFER TILE COLLECTION SYSTEM AND BARRIER WALL)
FORMER LAGOON SITE
*Hamptonburgh, New York*

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**TABLE E.1**

**SUMMARY OF HYDRAULIC PARAMETERS FOR THE SHALLOW AND BEDROCK AQUIFER**
**FORMER LAGOON SITE**
**HAMPTONBURGH, NEW YORK**

| *Hydraulic Unit* | *Hydraulic Conductivity (ft/day)* | *Estimated Average Saturated Thickness (ft)* | *Average Transmissivity ($ft^2$/day)* | *Average Horizontal Hydraulic Gradient* | *Groundwater Flux (ft /day)* | *(gpm)* |
|---|---|---|---|---|---|---|
| Shallow Aquifer | | | | | | |
| North Flow | 2.8 | 5 | 14 | 0.0335 | 212 (1)/674 (2) | 1.1 (1)/3.5 (2) |
| South Flow | 2.5 | 5 | 12.5 | 0.021 | 212 (1)/1405 (2) | 1.1 (1)/7.3 (2) |
| Bedrock Aquifer (3) | | | | | | |
| North Flow | 0.055 (4) | 120 | 6.6 | 0.024 | 750.8 | 3.9 |
| South Flow | 0.54 | 120 | 65 | 0.023 | 750.8 | 3.9 |

Notes:

(1) Flux through Shallow Component is due to lateral groundwater flow.
(2) Flux through Shallow Component is due to infiltration.
(3) Flux through Bedrock Component is due to lateral groundwater flow. The hydraulic conductivity for the northern flow is assumed to be similar to the Southern Flow Component.
(4) Based on one in situ hydraulic test.

TABLE E.2

SUMMARY OF CAPTURE ZONE CALCULATIONS
FORMER LAGOON SITE
HAMPTONBURGH, NEW YORK

| *Hydraulic Unit* | *Pumping Rate* | | *Transmissivity* | *Estimated Horizontal Hydraulic Gradient* | *Distance to Downgradient Stagnation Point* | *Width of the Capture Zone* |
|---|---|---|---|---|---|---|
| | *(gpm)* | *($ft^3/day$)* | *($ft^2/day$)* | | *(ft)* | *(ft)* |
| Water Table Aquifer | | | | | | |
| North Flow | 0.5 | 96.25 | 14 | 0.0335 | 33 | 103 |
| South Flow | 0.5 | 96.25 | 12.5 | 0.021 | 58 | 183 |
| Bedrock Aquifer | | | | | | |
| North Flow | 9 | 1732.5 | 65(1) | 0.024 | 176.5 | 555 |
| South Flow | 9 | 1732.5 | 65 | 0.023 | 184 | 579 |

Note:

(1) - Assumed transmissivity in the bedrock north flow component is similar to bedrock south flow component.

# ATTACHMENT I

# CAPTURE ZONE CALCULATIONS

## Sample Calculation - Shallow Aquifer Extraction Well Capture Zone Limits - North Flow Component

- Todd (1980) Equation to determine stagnation points.

$r_i$ = Distance to downgradient stagnation point = $r_c = \dfrac{Q}{2 \bullet \pi \bullet \tau \bullet i}$

Q = Pumping Rate
= 0.5 gpm

$0.5 \text{ gpm} \times 192.5 \dfrac{\text{ft}^3/\text{day}}{\text{gpm}} = 96.25 \text{ ft}^3/\text{day}$

T = Transmissivity
= T = K•b

K = Hydraulic Conductivity
= 2.8 ft/day

b = Saturated Thickness
= 5 ft.

T = 2.8 ft/day • 5 ft
= 14 $\text{ft}^2$/day

i = Horizontal Hydraulic Gradient
= 0.0335

$r_i = \dfrac{Q}{2 \bullet \pi \bullet \tau \bullet i} = \dfrac{96.25}{2 \bullet \pi \bullet 14 \bullet 0.0335}$
= 33 ft

∴ Downgradient Stagnation Point is 31 feet distant.

$\pi r_e$ = Diameter of Capture Zone Perpendicular to gradient at the pumping well

$\pi r_e$ = π • 31
= 103 ft

∴ Perpendicular Capture Zone diameter is 103 feet across

Sample Calculation - Shallow Aquifer Extraction Well Capture Zone Limits - South Flow Component

- Todd (1980) Equation to determine stagnation points.

$r_i$ = Distance to downgradient stagnation point = $r_c = \frac{Q}{2 \bullet \pi \bullet T \bullet i}$

Q = Pumping Rate
= 0.5 gpm

$0.5 \text{ gpm} \times 192.5 \frac{ft^3/day}{gpm} = 96.25\ ft^3/day$

T = Transmissivity
= T = K•b

K = Hydraulic Conductivity
= 2.5 ft/day

b = Saturated Thickness
= 5 ft.

T = 2.5 • 5
= 12.5 $ft^2$/day

i = Horizontal Hydraulic Gradient
= 0.021

$r_i = \frac{Q}{2 \bullet \pi \bullet \tau \bullet i} = \frac{96.25}{2 \bullet \pi \bullet 12.5 \bullet 0.021}$

= 58 ft

∴ Downgradient Stagnation Point is 58 feet distant.

$\pi r_e$ = Diameter of Capture Zone Perpendicular to gradient at the pumping well

$\pi r_e$ = π • 58
= 183 ft

∴ Perpendicular Capture Zone diameter is 183 feet across

## Sample Calculation - Bedrock Aquifer Extraction Well Capture Zone Limits - North Flow Component

- Todd (1980) Equation to determine stagnation points.

$r_i$ = Distance to downgradient stagnation point = $r_c = \dfrac{Q}{2 \bullet \pi \bullet T_i \bullet i}$

Q = Pumping Rate
= 9 gpm

$$9 \text{ gpm} \times 192.5 \frac{ft^3/day}{gpm} = 1732.5\ ft^3/day$$

T = Transmissivity
T = 67 $ft^2$/ day (according to RI data)

i = Horizontal hydraulic gradient
= 0.024

$$r_c = \frac{Q}{2 \bullet \pi \bullet T \bullet i} = \frac{1732.5}{2 \bullet \pi \bullet 0.024 \bullet 67}$$

= 177 ft

∴ Downgradient Stagnation Point is 176 feet away.

$\pi r_c$ = Diameter of Capture Zone Perpendicular to gradient at the pumping well
$\pi r_c$ = $\pi \bullet 177$
= 555 ft

∴ Perpendicular Capture Zone diameter is 555 feet across

Sample Calculation - Bedrock Aquifer Extraction Well Capture Zone Limits
- South Flow Component

- Todd (1980) Equation to determine stagnation points.

$r_i$ = Distance to downgradient stagnation point = $r_c = \dfrac{Q}{2 \bullet \pi \bullet T_i \bullet i}$

Q = Pumping Rate

= 9 gpm

$= 9 \times 192.5 \dfrac{ft^3/day}{gpm} = 1732.5\ ft^3/day$

T = Transmissivity

T = 67 $ft^2$/day (based on North Flow bedrock aquifer parameters)

i = Horizontal hydraulic gradient

= 0.023

$$r_c = \frac{Q}{2 \bullet \pi \bullet T \bullet i} = \frac{1732.5}{2 \bullet \pi \bullet 0.023 \bullet 67}$$

= 184 ft

∴ Downgradient Stagnation Point is 184 feet away.

$\pi r_c$ = Diameter of Capture Zone Perpendicular to gradient at the pumping well

$\pi r_c$ = π • 184

= 579 ft

∴ Perpendicular Capture Zone diameter is 579 feet across