A FEASIBILITY STUDY OF RAINFALL HARVESTING AND SMALL SURFACE-CATCHMENT SYSTEM FOR DRINKING WATER SUPPLIES CASE STUDY: TRAMMEL GAP COMMUNITY DICKENSON COUNTY, VIRGINIA

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Mr. Leman Kendrick, P.E., provided valuable input and reviewed the project design. Mr. Gary Dingus assisted in site selection and facilitated visits to the study site. Ms. Judy Poff edited the final document.

DISCLAIMER

Computations for this project were based on limited available information. Therefore, several assumptions were made as appropriate. Cost estimates were based on available information for other water projects and assumptions were made as appropriate. The final cost estimates were based on assumptions of this study and conditions for a specific site, the Trammel Gap community, and therefore, they may not be applicable to other areas.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Trammel Gap community in Dickenson County is a cluster of ten houses situated on an isolated ridge at an elevation of about 2800 feet above the sea level. Due to its high elevation and coal mining activities within the ridge, this community has no public water system or adequate groundwater. At present, residents of Trammel Gap obtain their drinking water by means of rooftop rainfall collection-cistern storage or the water is hauled to the community by truck from a water treatment plant. A public water line exists at the toe of the mountain. However, it is estimated that extending the public water system to the ridge will cost at least $30,000 per household.

This project was designed to study the feasibility of a small surface-water catchment-distribution system for the Trammel Gap community. The study entailed identifying a watershed in the vicinity of Trammel Gap where watershed runoff could be stored in a constructed reservoir. The reservoir water would then be conveyed by a pumping system and a pipeline up the incline to the top of the ridge, stored in a holding tank, and distributed to each house by pipelines. Some type of water treatment unit should be incorporated as well.

In this report, basic design components for the above system are presented. Approximate costs for each component of the project and the total cost are included. The surface-water in the reservoir needs to be treated to meet the National Drinking Water Standards for public water systems. Possible water treatment methods are discussed in the report. However, since water quality of the catchment surface is unknown, the method for water treatment and the associated water treatment costs are not included in the report.

The total estimated cost for the proposed project was $464,796 ($46,480 per household). This estimate does not include the expenses involved with water treatment, reservoir construction permit, and the possible need for a second pump station half way from the proposed reservoir to the ridge top water holding tank. The estimated project cost exceeds that for extending the public water line. Based on estimated cost, it was concluded that a surface- water catchment system for the size of Trammel Gap community is not economically feasible.

INTRODUCTION

Dickenson County is located in the southwestern region of Virginia within the Cumberland Plateau. Availability of groundwater in many ridge top communities of Dickenson County is limited due to high elevation. Some aquifers have been drained or the groundwater is contaminated due to the past mining activities.

The Cumberland Plateau Planning District has developed a long-term plan to bring public water supplies to many communities of Dickenson County. However, there are pockets of isolated communities where extending the public water lines is cost prohibitive because of their location on high elevation ridge tops. Families that live on these ridges are resistant to the suggestion of moving to lower areas, where safe and adequate drinking water is available, because of the sentimental value of land passed from generation to generation. The local government understands this situation and is very interested in finding cost- effective ways to deliver or provide safe water to these communities.

A project was initiated to study the feasibility of a small surface-water catchment-distribution system for an isolated ridge top small community. The study entails catching rainwater in a constructed reservoir within the watershed, conveying the water up the incline to the top of the ridge, storing it in a ridge top holding tank, and distributing the water by means of pipelines to the ridge top households. Some type of water treatment should be incorporated as well.

Trammel Gap, a cluster of ten households in Dickenson County, was selected as the site to conduct the feasibility study. This is a typical ridge top community located on an isolated ridge at an elevation of about 2800 feet above sea level. Because of the high elevation and the past coal mining activities in the area, this community has no public water or groundwater. A public water supply system exists at the toe of this mountain. However, the county engineer has estimated a cost of $30,000 per household to provide Trammel Gap with public water. Dickenson County cannot justify nor acquire the funding to go ahead with this project. At present, residents of Trammel Gap obtain their drinking water from rooftop rainfall collection- cistern storage or hauling water from a water treatment plant by truck to the community.

PROJECT GOAL

The goal of this project was to study the feasibility of using a surface water-catchment and distribution system to provide water to an isolated small ridge top community. Figure 1 shows a schematic view of the proposed design.

Specific Objectives

1. Conduct an analysis of the hydrologic data to determine the water balance in the watershed.
2. Select the most appropriate drainage area for the reservoir site and determine the required storage volume.
3. Design a reservoir in the selected site for water supply purposes.
4. Determine the pumping requirements.
5. Design a water distribution network to each household.
6. Discuss potential water treatment methods for the raw (reservoir) water.
7. Estimate the total project cost.

Design Specification

1. The water supply must be sufficient for a cluster of 10 households.
2. The reservoir should have a capacity to supply an average of 350 gallons per day of water to each household (4 persons per household). Therefore, the total water need is 108,500 gallons per month (1,302,000 gallons per year or 4.0 ac-ft/year).
3. An equivalent of two-month supply (217,000 gallons) should be available in the reservoir storage to assure adequate water supply during dry periods.
4. A holding tank to be installed on the highest possible location on the ridge top and should have capacity for a three-day supply of water.
5. Rainfall-runoff catchment will constitute the only source of water supply.
6. The reservoir dam should be designed to withstand a twenty-five year storm.
7. The water pressure at the pipe network for water distribution should be maintained at 40 pounds per square inch and the flow rate at 10 gallons per minute.

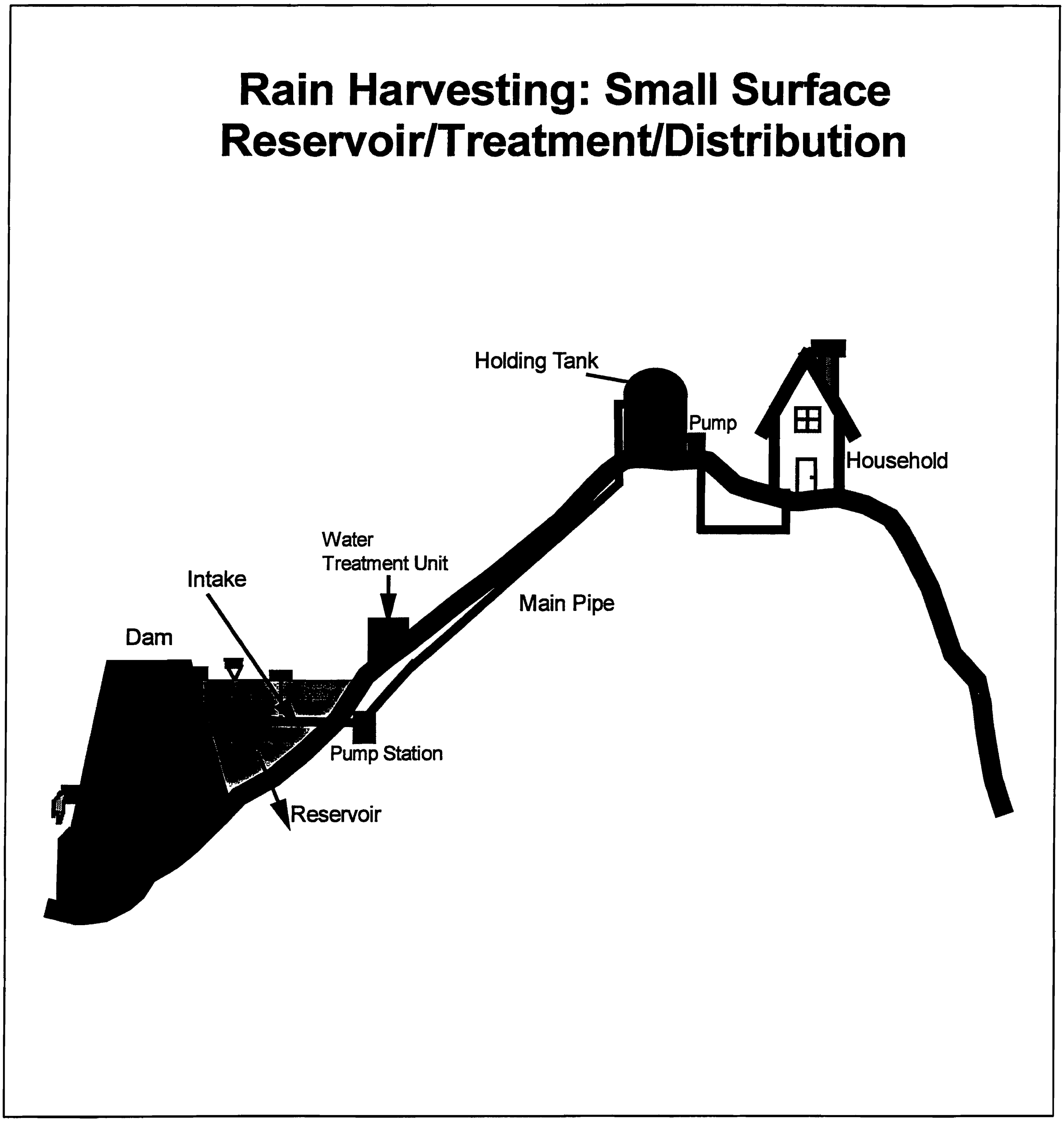

Figure 1. Conceptual Design

SYSTEM DESIGN

1. Watershed Selection and Required Storage Volume

The objective was to identify a watershed where adequate runoff water could be collected and stored in a reservoir near the watershed outlet. The reservoir location should be as close as possible to the ridge top holding tank. Longer distances between the reservoir and the holding tank would result in higher pumping cost, higher pipe installation costs, and higher pressure loss.

Two possible watersheds were identified on the USGS topographic map near the Trammel Gap (Appendix A). Areas for these watersheds were 24 and 137 acres, respectively. A water budget for the area was developed using long-term (1969-1994) hydrologic data from the John Flannagan Lake weather station. The water budget computations are documented in Appendix B and Appendix C. Using the water budget over the watershed area, potential monthly water yield for each watershed was determined. The smaller watershed is situated closer to the ridge top holding tank and would yield sufficient water to meet water demands for the Trammel Gap community. On a yearly basis, the required storage volume for the smaller 14-acre watershed was estimated as 30.1 ac-ft (Appendix D).

2. Reservoir Design

Detailed information and calculations for the reservoir design are given in Appendix E. A brief description is provided below. The reservoir design was based on a twenty-five year, 24-hour storm. The total dam height (44.22 ft) accounts for the normal water level elevation (29.81ft), flood storage depth (8.19ft), freeboard (0.581ft), and flow depth in the spillway (1.64ft). The top width of the dam was determined to be 19.32 feet. The bottom width of the dam was 220.52 feet and the volume of fill needed to construct the dam was 99,892 cubic feet. The emergency spillway had a maximum flow depth of 1.64 feet, top width of 61.9, and bottom width of 52.06 feet with side slopes of 3:1.

3. Pumping Requirements

The required head to pump water from the reservoir to the holding tank is 801feet. The main pipe length (4-inch PVC) from the reservoir to the holding tank will be 1308 feet. In this report, installation of two pumps in parallel (one station) at the reservoir site is suggested. However, a difference in elevation of more than 800 feet may require installation of a second pump station in series at a 400-foot interval between the first pump station at the reservoir and the holding tank.

4. Water Distribution Network

The size of the holding tank was based on the amount of water used per day and the amount needed for the emergency supply. A minimum of three-day water storage (10,500 gallons) is recommended as a safety feature in the event of a power failure.

Distances from the reservoir to the holding tank, and from the holding tank to each house were measured from the topographic map using a digitizer. A distribution network that included two-inch, four-inch, and six-inch pipe was designed (Figure 2). The options considered for water distribution from the holding tank to each household included a gravity distribution system, a pump driven system, and a pressure tank system. If a gravity system, the least expensive, is used, the holding tank would have to be raised an additional 92 feet in order to create the required 40 psi, pressure, in the pipelines. For this project, a 3- horsepower pump was considered as an economic and feasible option. The drawback of a pump driven system is that it requires continuos pumping, and again, an alternate source of energy in case of a power failure.

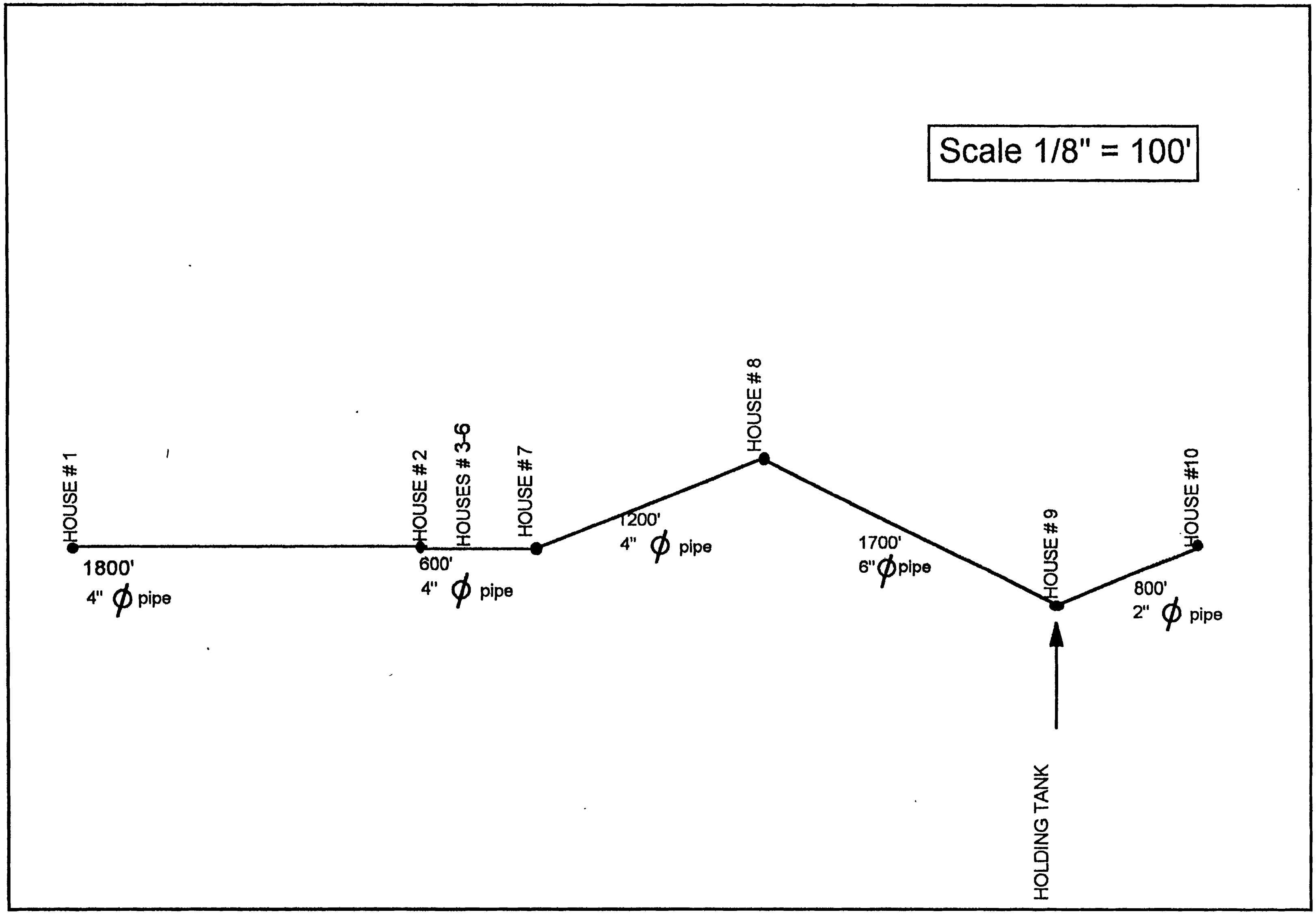

Figure 2. Water Distribution Network

5. Water Treatment Options

Several alternatives such as Point of Entry (POE) treatment and Point of Use (POU) treatment are available for individual households. However, Point-of-use (POU) and point-of-entry (POE) treatment systems are only applicable to private water supplies where groundwater or rooftop rainfall is used. To comply with surface water regulations and to ensure safe water, a small surface water reservoir would require the installation of a small water treatment system.

Several factors should be considered when selecting a small community drinking water treatment system. These include regulatory compliance, source water quality, operation, maintenance, and capital expenses. In general, for small systems using surface water sources, treatment requirements are driven by the Surface Water Treatment Rule, which requires filtration and disinfection of the water. However, small systems should apply technologies to meet requirements of the Safe Drinking Water Act only after exhausting all other possible options.

Selection of a water treatment system is unique to the conditions of the specific site. Lykins (1992) states that there are six major factors in the decision making process when choosing a treatment system: (1) quality and type of water source, (2) type and extent of contamination, (3) economics of scale and cost of water, (4) treatment requirements, (5) waste disposal requirements, (6) installation requirements

There are many types of water treatment systems available. Filtration, aeration, and disinfection are only a few of the treatment processes included in these systems. Several types of small water treatment systems are described in table 3 (NRC, 1996).

6. Telemetry

Operations costs are a major hindrance in providing adequate and safe drinking water to communities where populations depend on small water systems and community financial resources are limited. One approach to provide safe and cost-effective water is to employ some type of telemetry or remote management, that would enable the operator to significantly reduce and prioritize site visits and schedule maintenance.

7. Design Recommendations

Figure 3 shows recommended design components.

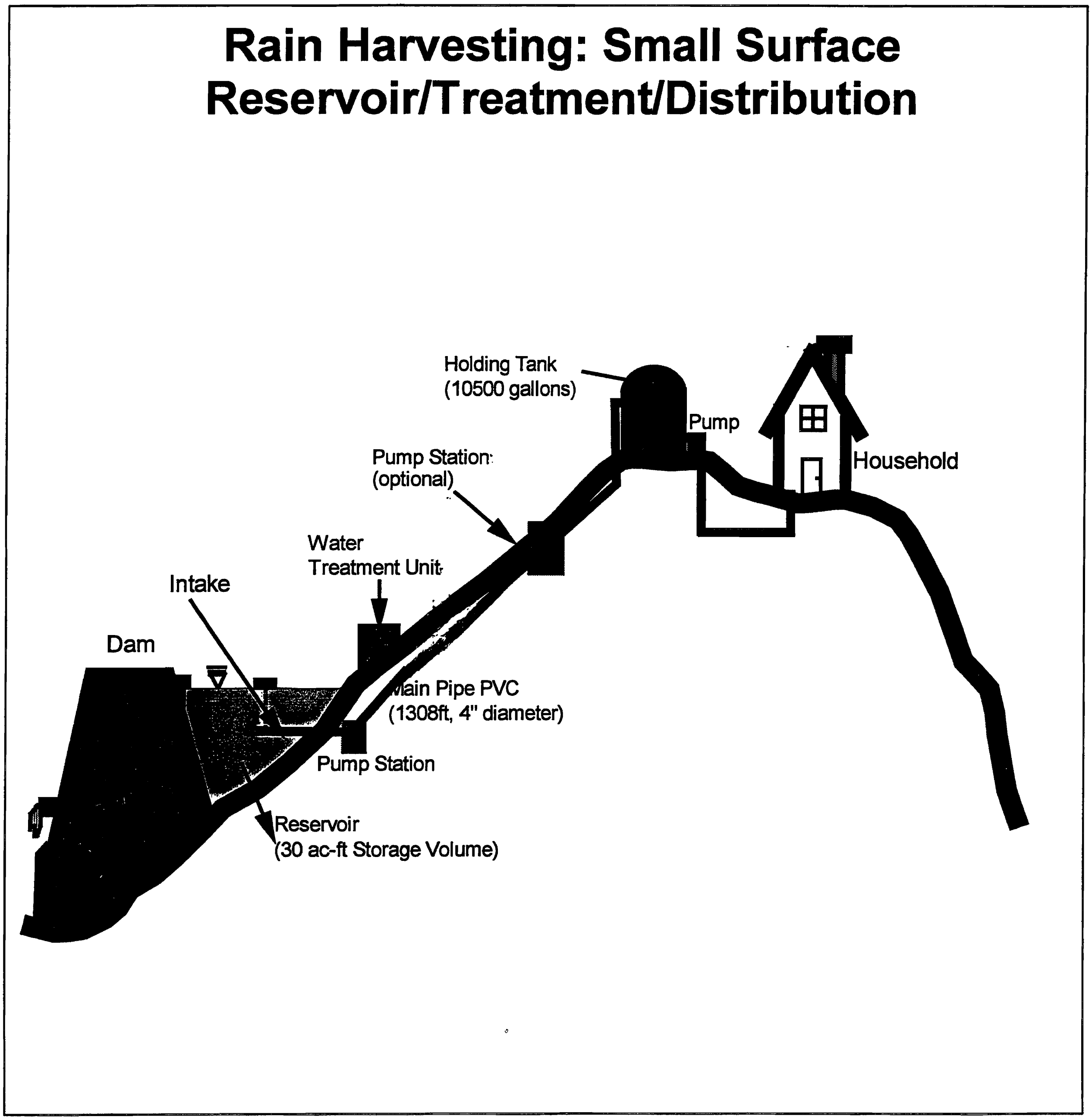

Figure 3. Recommended Design Components

PROJECT COST

Table 1. Cost Estimate for Reservoir and Dam Construction

		Quantity	Unit	Unit Cost	Cost
	Equipment:				
	On site fill (compacted)	3689	yd^3	$7.50	$27,667.50
	Land clearing	3	ac	$3,500.00	$10,500.00
	Mechanical spillway	135	ft	$1.00	$135.00
	Submersible pump	2		$1,000.00	$2,000.00
	Pipe to distribution tank (4" PVC)	1308	ft	$1.99	$2,602.92
	Seeding	2	ac	$2,500.00	$5,000.00
	Telemetry System: (Remote sensing in the pump station and/or in the tank)				$10,000.00
	Construction cost (does not include pipe installation or land clearing)		$		
	Pipe installation (main line)	1308	ft	$15.00	$19,620.00
	Pump station (includes housing, parallel pumps, etc.)	1		$150,000.00	$150,000.00
	Miscellaneous cost (engineering, power service, etc.)		$	35% of construction costs	$61,117.00
	Land Cost:				
	(May have to purchase the land where reservoir will be located)				$5,000.00
	Total Cost of Reservoir, Dam, Pump station, etc.				$293,642.42
	Water Treatment Cost:				
	(Depends on selected type of treatment)				Unknown

Table 2. Cost Estimate for Water Distribution System

		Quantity	Unit	Unit Cost	Cost
	Water holding tank				
	Storage Tank (includes installation)	1		$15,000.00	$15,000.00
	Concrete foundation	1		$5,000.00	$5,000.00
	Pipe network				
	Pressure reducer	10		$34.52	$345.20
	Pressure gage	10		$7.30	$73.00
	PVC pipes (to each house)				
	2"	800	ft	$0.40	$320.00
	4"	3600	ft	$1.99	$7,164.00
	6"	1700	ft	$3.81	$6,477.00
	Pipe installation	6100	ft	$15.00	$91,500.00
	Meters	10		$500.00	$5,000.00
	Valves				
	Gate valve				$1,100.00
	Air release valve				$1,500.00
	Blow-off valve				$700.00
	Miscellaneous cost (engineering, power service, etc.)			35% of construction costs	$37,275.00
	Total Cost of Distribution System				$171,154.20

Table 3. Total Cost Estimate

	Total Cost of Reservoir, Dam, Pump station				$293,642
	Total Cost of Water Distribution System				$171,154
	Grand Total Cost				$464,796*
	Total Cost per Household				$46,480*
	(Does NOT include the unknown costs listed below)				
	*Costs not included: Water treatment, second pump station at 400 ft elevation, costs involved with obtaining Corps of Engineers approval for reservoir construction, and operating costs.				

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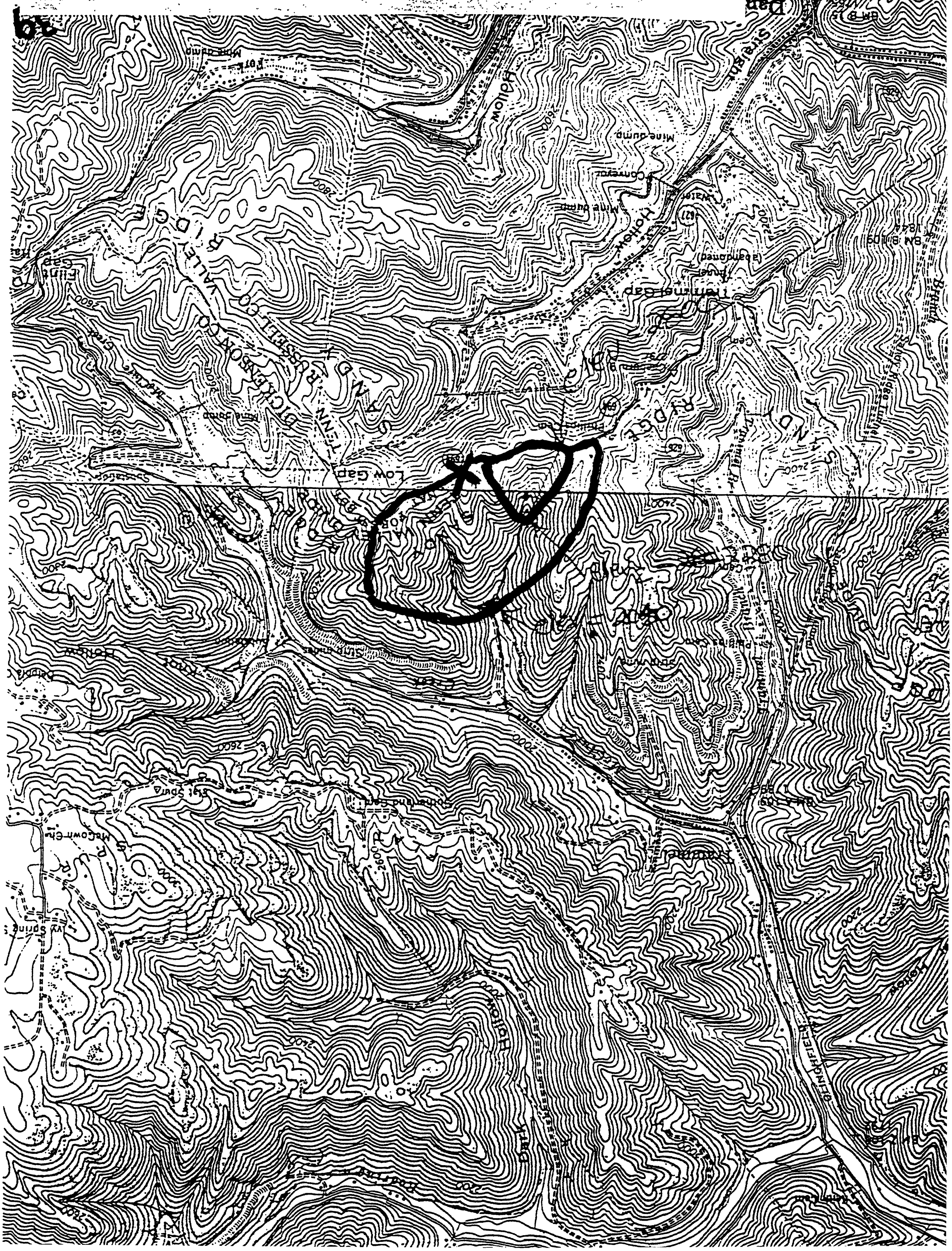
APPENDIX A. Topographic Map for Trammel Gap Area



APPENDIX B. Evapotranspiration Estimation

Evapotranspiration (ET) calculations were based on the average monthly temperature data and the Thornthwaite equation.

$$Ep = \left(\frac{10T}{I}\right)^{a}$$

Where,

Ep	=	Potential evapotranspiration (cm/month, in months of 30 days, with a day-length of 12 hours)
T	=	Average monthly air temperature (°C), calculated from daily means
I	=	Annual heat index, i.e. the sum of the 12 monthly heat indices, *i*,

Where:

$$i = \left(\frac{T}{5}\right)^{1.514}$$

a = $0.000000675I^3 - 0.000077I^2 + 0.01792I + 0.49239$

Average evapotranspiration values

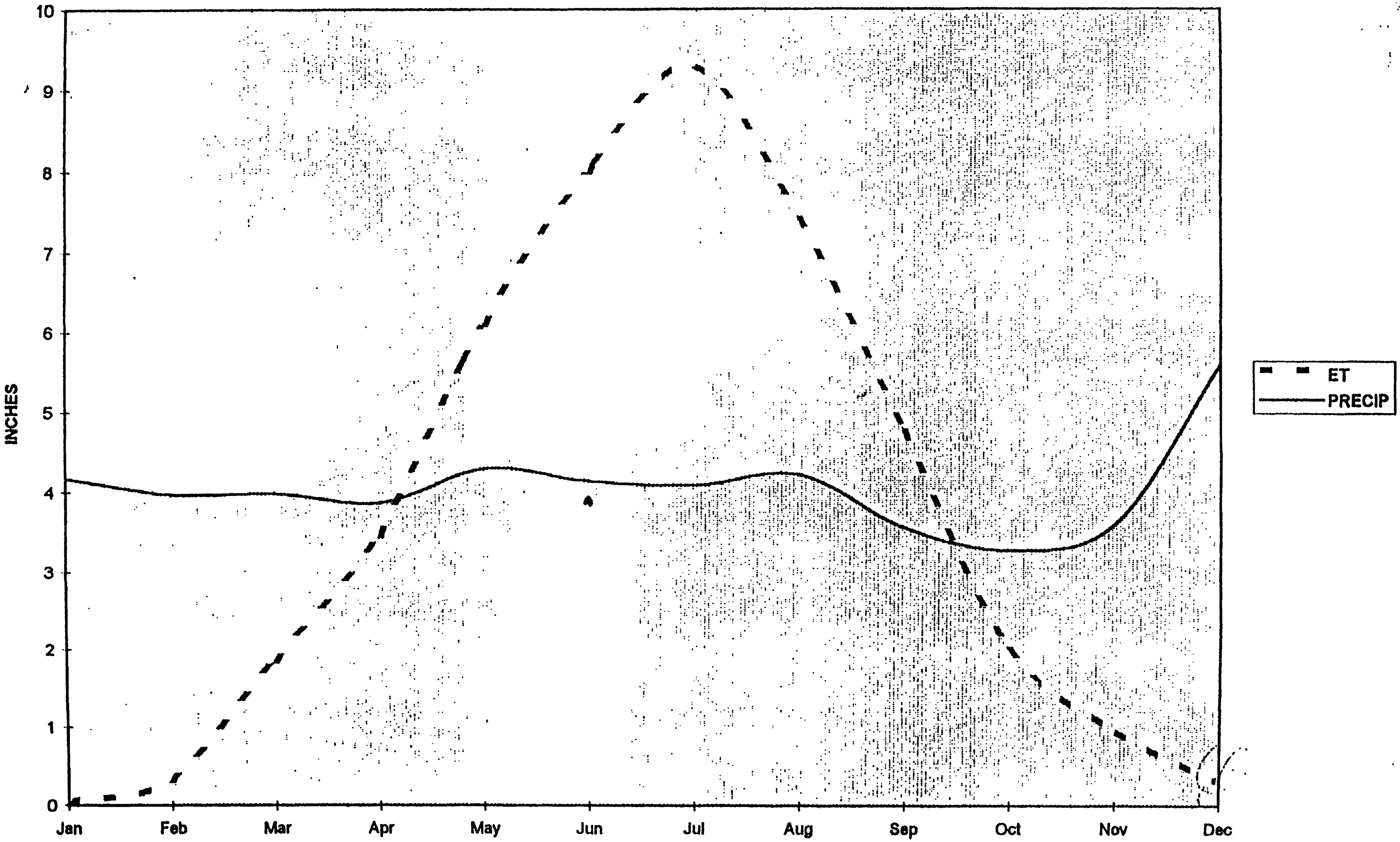
Month	Day Avg Temp (°F)	Day Avg Temp (°C)	I	A	Ep avg (cm/mo)	Lat. Corr. Factor	Ep avg correcte (cm/mo)	Ep avg correcte d (in/mo)
Jan	34.1	1.17	0.11	2.1	0.019	0.86	0.0166	0.0065
Feb	44.9	7.17	1.72	2.1	0.869	0.84	0.7299	0.2874
Mar	60.2	15.67	5.64	2.1	4.482	1.03	4.6163	1.8174
Apr	69	20.56	8.5	2.1	7.923	1.1	8.715	3.4311
May	78.2	25.67	11.9	2.1	12.623	1.22	15.4002	6.0631
Jun	84.4	29.11	14.4	2.1	16.439	1.23	20.2204	7.9608
Jul	87.9	31.06	15.88	2.1	18.827	1.25	23.534	9.2654
Aug	84	28.89	14.23	2.1	16.177	1.17	18.9273	7.4517
Sep	76.8	24.89	11.36	2.1	11.834	1.03	12.1891	4.7989
Oct	62.6	17	6.38	2.1	5.319	0.97	5.1598	2.0314
Nov	54.6	12.56	4.03	2.1	2.817	0.85	2.3945	0.9427
Dec	44.9	7.17	1.72	2.1	0.869	0.83	0.7212	0.2839
Σ i =			95.88					
Latitude (deg N) = 37								

APPENDIX C. Water Budget for Study Area

Month	Av. Monthly snow (in)	Water in snow (in)[1]	Rain Avg. (in)	Total Precipitation (Rain and snow) (in)	Evapo-transpiration avg (in/mo)	Deficit/ Surplus (in)[2]
Jan	7.36	0.736	3.44	4.176	0.0065	4.170
Feb	6.04	0.604	3.37	3.974	0.2874	3.687
Mar	2.38	0.238	3.75	3.988	1.8174	2.171
Apr	1.83	0.183	3.69	3.873	3.4311	0.442
May	0	0	4.3	4.3	6.0631	-1.763
Jun	0	0	4.14	4.14	7.9608	-3.821
Jul	0	0	4.09	4.09	9.2654	-5.175
Aug	0	0	4.22	4.22	7.4517	-3.232
Sep	0	0	3.55	3.55	4.7989	-1.249
Oct	0.81	0.081	3.19	3.271	2.0314	1.240
Nov	2.2	0.22	3.38	3.6	0.9427	2.657
Dec	22.32	2.232	3.37	5.602	0.2839	5.318
Total excess yearly rain						4.444

[1] Assumed as 10% of average snow
[2] Adjusted for evapotranspiration

RAINFALL DEFICIT
DICKENSON CO., VA



APPENDIX D. Cumulative One-Year Required Storage Volume for the Selected Watershed

Month	Deficit/ Surplus (inch)	Deficit/ Surplus (ft)	Area (ft^2)	Water Yield (ft^3)	Net Water Yield (ft^3)	Cum Water Yield (ft^3)	Cum Water Yield (gal)	Cum Water Yield (ac-ft)
Jan	4.1695	.347458	1044137	362794	329374	329374	2463900	7.56139
Feb	3.6866	.307217	1044137	320776	287356	616730	4613483	14.1582
Mar	2.1706	.180883	1044137	188867	155447	772177	5776312	17.7268
April	0.4419	.036825	1044137	38450	5030	777208	5813942	17.8422
May	-1.7631	-.14693	1044137	0	(33420)	743788	5563942	17.0750
June	-3.8208	-.3184	1044137	0	(33420)	710368	5313942	16.3078
July	-5.1754	-.43128	1044137	0	(33420)	676948	5063942	15.5406
Aug	-3.2317	-.26931	1044137	0	(33420)	643528	4813942	14.7734
Sep	-1.2489	-.10408	1044137	0	(33420)	610108	4563942	14.0061
Oct	1.2396	.1033	1044137	107859	74439	684547	5120789	15.7150
Nov	2.6573	.221442	1044137	231215	197795	882343	6600408	20.2558
Dec	5.3181	.443175	1044137	462735	429315	1311658	9811923	**30.1115**

APPENDIX E. Reservoir Design

Design Runoff rates

The reservoir design was based on a 25-year storm of 24 hours duration. The rainfall amount of this location was determined using the Weiss equation as follows:

$$I = 0.0256(C - A)x + 0.000256[(D - C) - (B - A)]xy + 0.01(B - A)y + A$$

Where,

I	=	rainfall amount in inches
X	=	return period variate
Y	=	duration variate
A	=	2-year, 1-h rainfall
B	=	2-year, 24-h rainfall
C	=	100-year, 1-h rainfall
D	=	100-year, 24-h rainfall

For this case, the return period variate was 25.3 and y = 100 (Schwab, 1993). A = 1.4, B = 2.9, C = 3.0, D = 5.9 were obtained from the respective U.S. rainfall frequency maps for 1 and 24-hr long storms and for return periods of 2 and 100 years (Schwab, 1993). Accordingly, I was determined to be 123.01 mm.

Using the Soil Conservation Service method, the direct surface runoff depth was determined as follows

$$Q = \frac{(I - 0.2S)^2}{I + 0.8S}$$

Where,

Q	=	direct surface water runoff depth in mm
I	=	storm rainfall in mm
S	=	maximum potential difference between rainfall and runoff in mm, starting at the time the storm begins

S was determined by

$$S = \frac{25400}{N} - 254$$

Where N is the Curve Number. In this case, it was 79 which corresponds to a hydrological condition for woodland, pasture, or range land cover.

$$S = \frac{25400}{79} - 254 = 67.5mm$$

The maximum length of flow was determined to be 0.7 inch from the topographic map. Therefore, the watershed gradient was determined to be the difference of 2800 and 2280ft (elevation between most remote point and outlet) over 1400ft (length), that is 0.37.

$$Q = 67.75mm\left(\frac{1m}{1000mm}\right) \times 9.66ha = 0.654m \cdot ha$$

The time of concentration in minutes, T_c was determined to be 3.03 min by

$$T_c = 0.0195L^{0.77}S_g^{-0.385}$$

Where S_g is the watershed gradient, 0.37, and L is 426.72m.

The rainfall intensity in mm/h, i, was calculated as 123.01/(3.03/60) or 2435.44mm/h.

The design peak runoff rate can now be calculated as

$$q = 0.0028CiA = 9.88\,{}^{m^3}\!/_{s}$$

Where A is the watershed area and C is 0.15 for good and mature woodland.

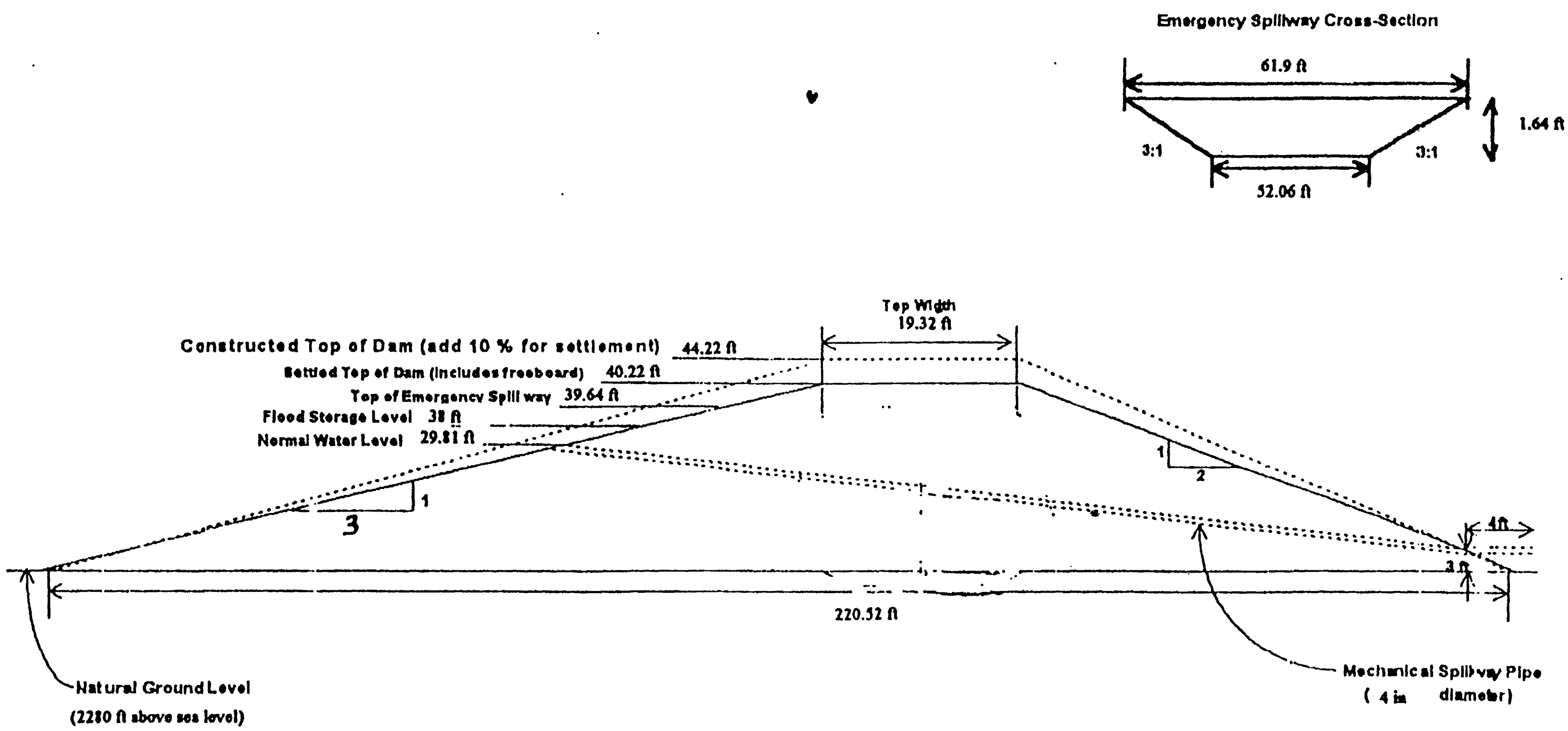
The width of the vegetated waterway, L, was calculated by

$$q = 0.55CLh^{3/2}$$

Where C was assumed to be 3.2 for a straight inlet, and maximum depth of flow of 0.5 m or 1.64ft was used. In this manner, L was determined to be 52.06 ft.

Freeboard was designed to account for flood storage requirements (67.75mm or 5.57 ac-ft, watershed storage (30.111 ac-ft), a wave height of 0.089 ft, and a frost depth of 0.5 ft. It was calculated to be 8 inches, including a factor of safety.

The total height of the dam included the normal water level elevation (29.81ft), flood storage depth (8.19ft), freeboard (0.581ft), and flow depth in the spillway (1.64ft). The normal water level, flood storage, emergency spillway, settled top of dam, and settlement height are 29.81, 38, 39.64, 40.22, and 44.22 feet, respectively. The top width of the dam was determined to be 19.32 ft. The bottom width of the dam is 220.52 feet, and the volume of fill needed to construct the dam is 99,892 cubic feet. The emergency spillway had a maximum flow depth of 1.64 feet, top width of 61.9, and bottom width of 52.06 feet with side slopes of 3:1.



Emergency Spillway Cross-Section
61.9 ft
1.64 ft
3:1
3:1
52.06 ft
Top Width
19.32 ft
Constructed Top of Dam (add 10 % for settlement) 44.22 ft
Settled Top of Dam (includes freeboard) 40.22 ft
Top of Emergency Spill way 39.64 ft
Flood Storage Level 38 ft
Normal Water Level 29.81 ft
1
3
1
2
4 ft
3 ft
220.52 ft
Natural Ground Level
(2280 ft above sea level)
Mechanical Spillway Pipe
(4 in diameter)

APPENDIX F. Water Treatment Options

	Type of Treatment	Process	Appropriate Water Quality and Performance Capabilities	Monitoring and Operating Requirements	Suitability for Small Systems
1	Coagulation/ Filtration	Employs chemicals to coagulate and destabilize suspended solids in the water so they can be removed by sedimentation and filtration.	Capable of removing turbidity, color, viruses, bacteria, protozoans such as *Giardia*cysts and *Cryptosporidium* oocysts, and disinfection byproduct precursors. Challenging conditions for treatment are cold water (5 °C or less) and turbidities of 10 NTU and lower. Presence of algae in the raw water can make treatment difficult due to clogging of filters.	Resources in terms of operator training and experience are limited for small systems.	Variations of coagulation/filtration treatment train are marketed as package plants. The use of high-rate sedimentation or solids removal processes and use of filtration rates of 12 to 17 m/h is important to make affordable systems. May need to provide a separate water storage facility at the site to attain adequate CT values
2	Dissolved Air Flotation	Raw water is coagulated and flocculated. In contrast to sedimentation, flocculated water flows to a basin where a cloud of microscopic bubbles floats the floc to the water surface. The bubbles are formed by injecting water (recycle stream) containing air dissolved at high pressure into flocculated water as it enters the basin.	Treats algae laden waters, cold waters, waters supersaturated with air, highly colored waters, and waters with low turbidity and alkalinity. Not appropriate for treating turbid raw waters and when clay and silt are present. Excellent for treating highly colored, soft, and low-turbidity waters.	Similar to coagulation/filtration systems.	DAF is more complex than coagulation/filtration system because of the need to control the recycle flow stream and saturator operation. Pre-engineered package treatment plants are available.
3	Diatomaceous Earth Filtration	Primarily used for particulate contaminant removal. Particulate matter is strained from the water at the surface of a cake of diatomaceous earth (fine-grade material composed of diatom fossil remains) placed on septa or filter leaves. The cake (precoat) is put on the filter by recirculating a slurry of DE through the filter. Flow is stopped when filter reaches capacity.	Raw water quality should be excellent and needs to be determined before installation of a DE filtration system. Low capability in removing bacteria, viruses, and dissolved constituents. Very effective in removing *Giardia* cysts and *Cryptosporidium* oocysts. Can remove algae to a high degree. Disinfection is necessary after filtration.	Simpler than coagulation/filtration because coagulant chemicals are rarely used. DE plant operators need mechanical skills to operate the precoat pumps, pipes, valves, mixers, and body feed pumps. Filters are operated intermittently (not 24 hour a day).	Well suited for small systems with waters of low turbidity, color and organic matter. Disinfection is necessary.
4	Slow Sand Filtration	Some inert suspended particles are physically removed from water and biological action breaks down some organic matter in the sand bed and is a key in the effectiveness of slow sand filters. Disinfection takes place after filtration. Storage is necessary to equalize production and demand since flow is operated at a steady rate.	Raw water quality appropriateness is limited. Turbidity < 5NTU, algae < 5 μg/L, iron < 0.3 mg/L, manganese <0.05 mg/L. Low capability in removing disinfection byproduct precursors or color. Clay content in source waters is a problem. Excellent in removing microorganisms except in cold waters (below 10 °C). Removal of total organic carbon, pesticides, and trihalomethane is achieved by installing a granular activated carbon sandwich filter to the slow sand filtration system.	Monitoring and operating a slow sand filter is not complicated, requies a couple of hours a day. Cleaning the filter is necessary. Replacing sand is labor intensive.	Package plants available. Suitable for small systems that must pretreat (GAC) the surface water before the slow sand filtration. If no pretreatment is applied, then slow sand filtration can only be applied to high quality surface waters.
5	Bag and Cartridge Filters	Developed specifically for small to very small systems. Water passes through a pressure vessel containing a woven bag or cartridge with a wound filament filter. Proper selection of cartridges and bag filter's pore size is critical. Pressure drop indicates when bag or cartridge needs to be replaced.	Source water should be of higher quality than for slow sand filtration. Not effective in removing bacteria, viruses, dissolved particulates and waters with high turbidity. Good at removing larger microbial contaminants such as *Giardia* cysts and *Cryptosporidium* oocysts	Simple monitoring requirements. Disposal of bags or cartridges is simple since they do not remove toxins but, disinfection is necessary to inactivate microbes.	Appropriate for only high quality surface waters since bags and cartridges do not remove chemical contaminants and small viruses. Best suitable for systems of fewer than 500 persons.