# ESTIMATING COSTS OF OFF-STREAM IRRIGATION STORAGE RESERVOIRS

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# Estimating Costs of Off-Stream Irrigation Storage Reservoirs

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## INTRODUCTION

Lack of adequate water sources has limited the ability of many Alabama farmers to adopt irrigation. In many parts of the state, ground water sources are either inadequate or impractical to develop for irrigation. Surface water sources such as streams often do not have sufficient flow during the growing season in Alabama to provide enough water for irrigation.

*Water harvesting,* the collection and storage of surface water during the off-season, when rainfall and stream flows are high, can make irrigation possible in areas where direct pumping from streams, lakes or wells is not feasible. The most common type of water harvesting is construction of dams and reservoirs directly on streams. However, on-stream impoundments are often impractical, either because streams are not located on drainage basins suitable for reservoir construction, or because stream flows are so high in fall, winter or spring that dams of the size and complexity that would be needed are not economically feasible.

Another water harvesting alternative is to build off-stream storage reservoirs, pumping water from the nearby stream to fill the reservoir during the high stream flow period. Water is then pumped from this storage reservoir during the growing season to irrigate crops. Off-stream irrigation storage has potential to greatly expand agricultural irrigation capacity in Alabama. This practice has proven feasible under the right conditions, and has been put to use already at some sites in Alabama.

The feasibility of off-stream water storage for irrigation depends on many factors, including seasonal stream flow rates, availability of suitable acreage for a reservoir, distance to crops to be irrigated, and the cost versus benefits of this type of irrigation for the crops to be grown. Reservoir construction is a key cost factor to be considered.

This investigation was undertaken to examine the possibility of estimating reservoir construction costs in Alabama under various conditions likely to be encountered. Reservoir construction costs will vary, depending on terrain characteristics, geology of the site, local labor and equipment costs, and the storage capacity needed. For a given reservoir capacity, the surface slope and conformance of the terrain determine the amount of excavation and/or earth fill required, which usually is the largest cost factor where on-site soil has adequate natural sealing capability. The geology of the site determines whether some type of liner (other than compaction of on-site soil) will be needed for adequate water retention in the reservoir. Liners, of either the soil amendment type, such as Bentonite or soda ash, or of plastic or rubber, can increase costs significantly.

## METHODS

Since earth moving is a primary cost factor for any constructed reservoir, the investigators first developed a spreadsheet analysis (using Microsoft Excel) to determine the amounts of excavation, borrow and fill required for any given storage volume. This model includes variables for relevant factors in producing the required excavation, borrow and fill volume, such as land slope, depth vs surface area, levee width and side slope, freeboard, and shrinkage

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of borrow excavation.

Figure 1 is a spreadsheet printout which displays the variables, with example calculations for a 300-acre-foot hillside reservoir and a 100-acre-foot levee reservoir. Figure 2 is a definition sketch from the program showing the various dimensions and slopes used in the calculations. The spreadsheet program is designed for computing excavation and fill requirements for reservoirs that are square in plan and located on either flat or sloping land surfaces, where levees will be required on either three or four sides.

The second step in the estimating process was determining costs for excavation and grading equipment and labor, establishing vegetation to stabilize levees, and installing various liner materials if needed. Liner materials considered as relevant for Alabama conditions include traditional soil amendment materials, soda ash and Bentonite, and several types of plastic or rubber liners.

The specific liner applications studied were soda ash at 0.15 pounds per square foot, 200-mesh Bentonite at 3 pounds per square foot in two layers, or 1.5 pounds per square foot in one layer, 30-mil PVC plastic, 40-mil HDPE plastic, and 45-mil EPDM rubber. A survey of representative suppliers was conducted to determine prevailing costs for these items, including installation.

The different types of liner would be appropriate for different sites in Alabama, depending on the particular geology of the given site. It should be noted that other suitable liner materials are available. Those listed are some of the more commonly used and the costs of other liner types should be within the range of those presented in this report.

The cost of earth moving was combined with liner costs to derive an estimated total construction cost for any desired water storage volume. Costs of other site work such as clearing, and of surveying and professional engineering consultation, were not included. Also not included were estimates of costs for associated equipment such as pumps and water lines. Costs for these items are highly variable and may or may not be required on any specific site.

# RESULTS AND DISCUSSION

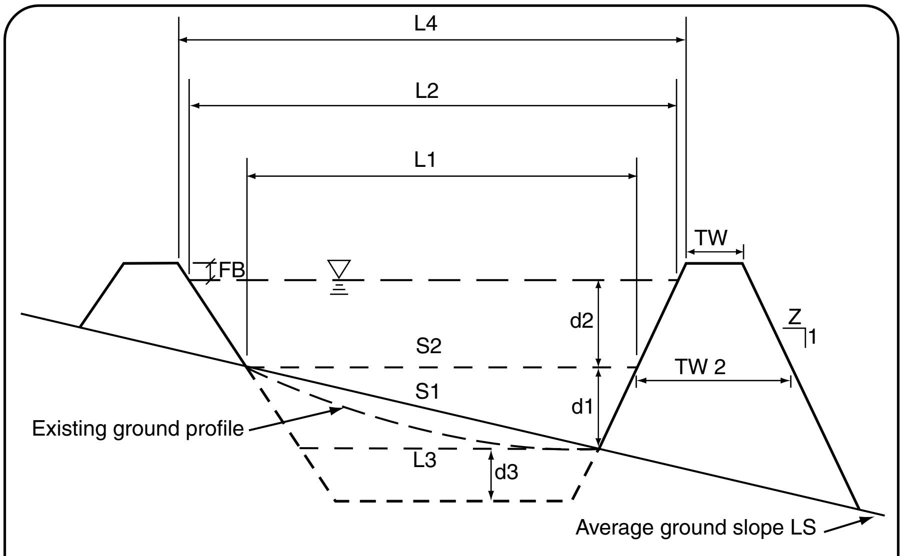
Table 1 shows examples of the primary result of the investigation in terms of derived data, estimated costs for irrigation storage reservoirs of various sizes, with and without liners. For 100-acre-foot capacity, these estimates range from about $35,000 for a reservoir needing no liner to about $282,000 for a reservoir with an EPDM rubber liner. Table 2 shows representative costs determined for the various types of liners that might be used. Computations of estimates in Table 1 also include cost of establishing vegetation to stabilize levees, determined to be about $350 per acre, and the

**FIGURE 1. EXAMPLE CALCULATIONS SHOWING SPREADSHEET PROGRAM VARIABLES**

| | Reservoir type | Hillside | Levee |
|---|---|---|---|
| INPUTS | Reqd. Storage (ac-ft) | 300 | 100 |
| | Land slope (**LS**, %) | 1.0 | - |
| | Depth (**d1**, ft) | 9.5 | - |
| | Depth (**d2**, ft)[1] | 4.0 | 6 |
| | Top width (**TW**, ft) | 12 | 12 |
| | Side slope (**Z**) | 2.5 | 2.5 |
| | Profile factor (**PF**)[2] | 2 | 1 |
| | Freeboard (**FB**, ft) | 2 | 2 |
| | Length for levee reservoir (**L1**, ft) | - | 735 |
| | Fill shrinkage factor (%) | 20 | 20 |
| OUTPUTS | **L1** | 974 | 735 |
| | **L2** | 994 | 765 |
| | **L3** | 926 | 735 |
| | **L4** | 1004 | 775 |
| | **TW2** | 42 | - |
| | **A1** | 624.625 | - |
| | **A2** | 162 | 256 |
| | Volume of fill (**VF1**, cu yd) | 57775 | - |
| | Volume of fill (**Vf2**, cu yd) | 24378 | 29848 |
| | Total fill (**VT**, cu yd) | 82153 | 29848 |
| | Volume excavated (**Vexc**, cu yd) | 77402 | 35817 |
| | Volume excavated (**Vexc**, ac-ft) | 48 | 22 |
| | Reservoir surface area (ac) | 22.67 | 13.43 |
| | Storage (**S1**, ac-ft) | 197 | - |
| | Storage (**S2**, ac-ft) | 89 | 77 |
| | Total storage (**ST**, ac-ft)[3] | 286 | 100 |
| | Depth of below ground excav. for levee reservoir (**d**, ft)[4] | - | 1.8 |
| | Borrow excav. reqd. (cu yd)[5] | 21182 | 35817 |
| | Borrow excav. reqd. (ac-ft) | 13 | 22 |
| | Depth of excav. below **L3** (ft) | 0.7 | - |

[1] When a hillside reservoir has a levee on only three sides, input d2 = 0 and adjust d1 until the desired storage is obtained.
[2] Profile factor (PF) for a levee reservoir is always 1.
[3] Adjust inputs until required storage is obtained.
[4] Depth required for total borrow excavation.
[5] Borrow excavation for the hillside reservoir is that in excess of the excavation within the reservoir (Vexc). If land slope is very small, decrease d1 and increase d2 to keep surface area reasonable. The borrow excavation required has been increased by the fill shrinkage factor.

**FIGURE 2. DEFINITION SKETCH FOR RESERVOIR DIMENSION VARIABLES**




S1 = storage between lines L1 and L3 FB = freeboard depth
S2 = storage between lines L1 and L2 Ls = average ground slope of the site in percent

Notes: When the existing ground profile is not a straight line, the Profile Factor indicates the ratio of excavation below the existing ground line compared to the volume between line L3 and the average ground slope. For example, a PF of 3 would indicate the actual excavation below the existing ground profile is 1/3 of that below the average ground slope.
For a levee reservoir, assume a flat ground surface. LS is then zero and d1 is zero also. Lines L1 and L3 become the same. Input an assumed value for L1 and d2 until the desired storage is obtained.
The Fill Shrinkage factor is a number indicating the percent increase in borrow required to produce the required fill. For example, a factor of 20% would mean 120 cu yds of borrow would be required to produce 100 cu yds of compacted fill.

prevailing cost of earth-moving work in Alabama reservoir construction, determined to be about $1.00 per cubic yard. Note that increasing (or decreasing) fuel prices will have a direct impact on earth moving costs.

In general, Table 1 shows that reservoirs needing no liner usually can be constructed at least cost by minimizing the amount of fill needed. Usually, this means holding reservoir depth to a minimum. For example, the table shows that a 100-acre-foot reservoir with a 10-foot depth will have a surface area of 10.7 acres and require 33,000 cubic yards of fill, while a same-volume reservoir with 15-foot depth will have a surface area of 7.7 acres and require 41,000 cubic yards of fill.

As can be seen in Table 1, the program shows that where liners will be required, minimizing the surface area of the reservoir generally results in least cost. For the cheapest type of liner, soda ash, the cost difference is rather small but still significant. For example, Table 1 shows that a 100-acre-foot reservoir with a surface area of 10.7 acres would cost about $97,000, while a same-capacity reservoir with a surface area of 7.7 acres would cost about $88,000.

Where the geology of the site indicates that more expensive liners would be called for, the cost differentials are much greater. For example, Table 1 shows a 100-acre-foot reservoir with 7.7 acres surface area would cost about $179,000 if lined with EPDM rubber, while a same-size reservoir with 10.7 acres surface area would cost about $282,000, well over $100,000 more.

The table shows estimated costs for example reservoirs with all liner types investigated except the 30-mil PVC plastic. This type liner was omitted because when costs of an additional soil cover needed to prevent degradation of the plastic by sunlight are included, total costs approach or exceed those for heavier-gauge and more durable HDPE plastic.

Generally, liners are considered only when natural sealing methods do not appear to offer adequate water retention. Table 1 shows that while earth-moving is generally the largest cost factor for any reservoir needing no sealing beyond compaction of on-site soil, even the least expensive liner materials are likely to exceed earth-moving costs.

In addition to cost of liner materials and installation, other factors such as water quality and availability, ease of installation, and durability of materials may be relevant in choosing a liner. For example, HDPE plastic requires availability of expert installers, while EPDM rubber does not. Plastic or rubber liners (types not requiring soil cover) may provide better water quality. Water quality parameters monitored over a four-year period have shown consistently high water quality at a 140 acre-foot research and demonstration reservoir constructed at the Tennessee Valley Research and Experiment Station at Belle Mina, Alabama, and lined with 40 mil HDPE.

The spreadsheet analysis developed in this investigation also produces useful curves, examples of which are shown in Figures 3-8. These figures show, for various storage capacities of hillside reservoirs, the relationships between depth of water and fill, and depth of water and surface area.

**TABLE 1. ESTIMATED COSTS FOR IRRIGATION STORAGE RESERVOIRS**

| Storage (ac-ft) | Depth (ft) | Area (ac) | Fill (cu yd) | Estimated Costs (per reservoir/per ac-ft) w/o liner | w/bentonite[1] | w/bentonite[2] | w/HDPE | w/EPDM | w/soda ash[3] |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 10 | 10.7 | 33,000 | $35,000 | $239,000 | $137,000 | $221,000 | $282,000 | $97,000 |
| | | | | $350 | $2,390 | $1,370 | $2,210 | $2,820 | $970 |
| 100 | 15 | 7.7 | 41,000 | $43,000 | $189,000 | $116,000 | $177,000 | $179,000 | $88,000 |
| | | | | $430 | $1,890 | $1,160 | $1,770 | $1,790 | $880 |
| 200 | 10 | 21 | 50,000 | $52,000 | $403,000 | $203,000 | $418,000 | $538,000 | $175,000 |
| | | | | $260 | $2,015 | $1,015 | $2,090 | $2,690 | $875 |
| 200 | 15 | 15 | 66,000 | $68,000 | $354,000 | $211,000 | $330,000 | $414,000 | $158,000 |
| | | | | $340 | $1,770 | $1,055 | $1,650 | $2,070 | $790 |
| 300 | 10 | 30 | 66,000 | $69,000 | $574,000 | $354,000 | $592,000 | $762,000 | $246,000 |
| | | | | 230 | $1,913 | $1,180 | $1,973 | $2,540 | $820 |
| 300 | 15 | 21.5 | 88,000 | $91,000 | $412,000 | $208,000 | $466,000 | $587,000 | $216,000 |
| | | | | $303 | $1,373 | $693 | $1,553 | $1,957 | $720 |

[1] Treatment rate 3 lbs/sq ft placed in two layers; [2] Treatment rate 1.5 lbs/sq ft placed in one layer; [3] Treatment rate 0.15 lbs/sq ft in one layer.

NOTE: Costs in this table include costs for earth work, liner and installation, and vegetation. Clearing, embankment foundation treatment, irrigation piping and pumps, engineering services or other costs are not included. Other miscellaneous costs associated with construction of the reservoir may range from 5 to 10 percent or more depending on the complexity of the site. Unit costs used in the computations are as follows:

| | |
|---|---|
| Earth fill | $1.00/cuyd |
| Vegetation | $350 /ac |
| Bentonite | $145 /tn |
| Soda Ash | $0.16 /lb |
| HDPE | $0.40 / sq ft (Installed cost) |
| EPDM | $0.53 / sq ft (Installed cost) |

# CONCLUSIONS

This report presents a procedure useful for estimating off-stream water storage reservoir construction costs in Alabama under various conditions likely to be encountered. Exact costs of particular installations will of course vary to some extent from costs predicted by any generalized estimating procedure. However, the estimates produced by the procedure outlined in this report should prove useful to anyone considering such an undertaking and wanting to determine the least cost approach suitable to their site, conditions and needs. This estimation procedure should also be useful to funding agencies and private or governmental agencies interested in irrigation as a planning tool for agricultural development in Alabama. Further, the procedures presented here should be applicable to other states or regions with appropriate adjustments to suit conditions prevailing in other regions.

The spreadsheet program developed in this investigation allows a competent user to quickly explore various scenarios in reservoir construction and compare construction cost estimates by changing various dimension and land contour inputs. The program will be available for use by qualified NRCS and Extension personnel assisting farmers and others interested in the possibilities of off-stream irrigation storage reservoirs. The program should be used only by individuals familiar with the engineering principles involved in reservoir construction.

Personnel using the program should be aware of the need for a geological study of any site considered for an off-stream storage reservoir, in order to determine whether a liner might be needed. Qualified NRCS personnel or professional engineering firms can provide the best possible evaluation of a site's water-holding capacity, and a recommendation as to the type of liner needed, if any.

**TABLE 2. TYPICAL RESERVOIR LINER COSTS**

| Product | Material | Installation | Total cost |
|---|---|---|---|
| HDPE, 40 mil | $0.25/sq ft | $0.15/sq ft | $0.40/sq ft |
| PVC, 30 mil | $0.25/sq ft | $0.10/sq ft | $0.35/sq ft |
| EPDM, 45 mil | $0.38/sq ft | $0.15/sq ft | $0.53/sq ft |
| Bentonite, | $0.085/lb (50lb bag) | – | – |
| 200 mesh | $0.08/lb (100lb bag) | – | – |
| | $0.0725/lb (per ton) | – | – |
| Soda Ash | $0.16/lb | – | – |

Notes: Costs listed are as estimated in December 2000. PVC liners require a soil cover. This cost is not included here. PVC and EPDM may be installed with local crews under the guidance of an experienced supervisor. Costs for installation supervision average $0.05/sq ft. Per ton cost for Bentonite assumes very large quantities.

**FIGURE 3. DEPTH OF WATER VS FILL FOR 100 AC-FT HILLSIDE RESERVOIR**

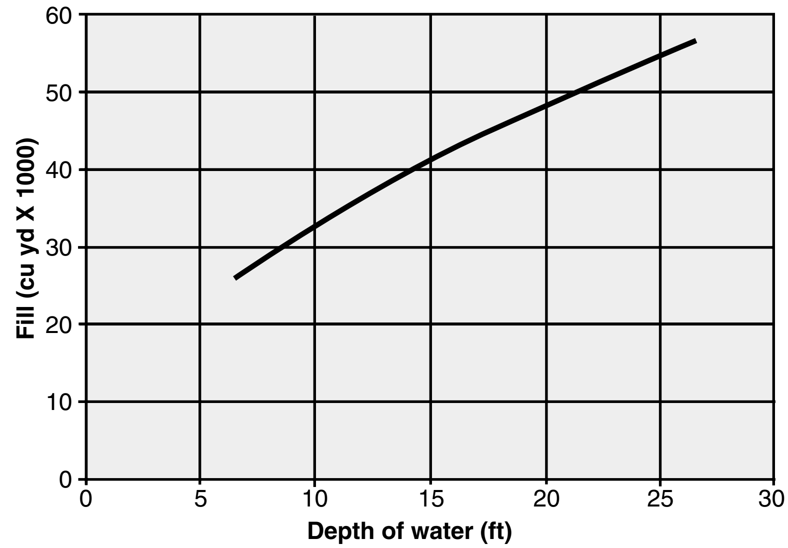



**FIGURE 4. DEPTH VS SURFACE AREA FOR 100 AC-FT HILLSIDE RESERVOIR**

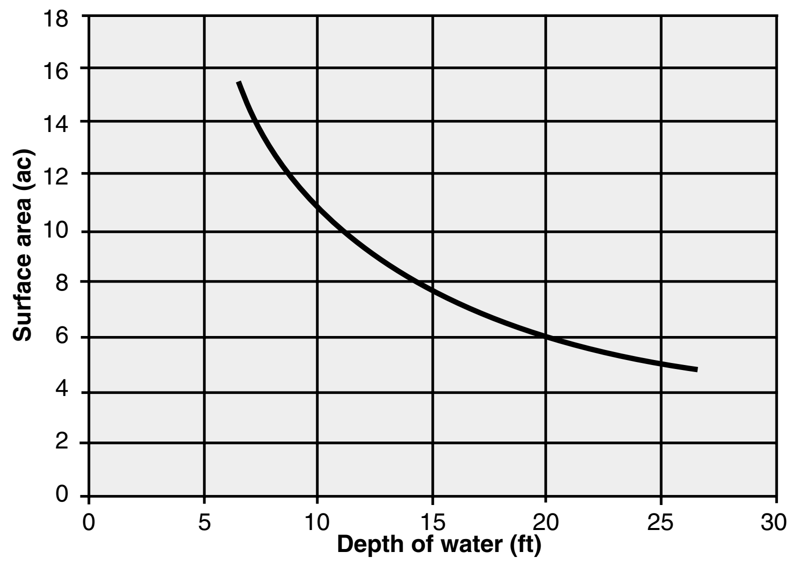



**FIGURE 5. DEPTH OF WATER VS FILL FOR 200 AC-FT HILLSIDE RESERVOIR**

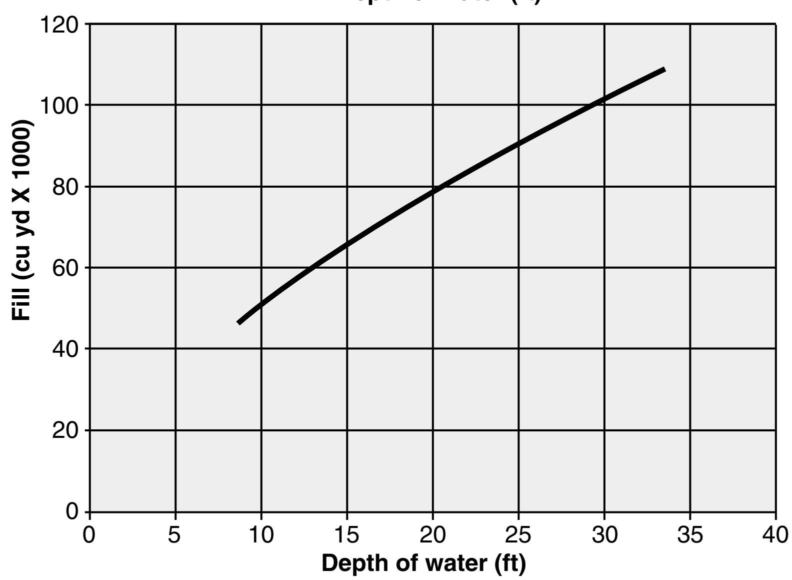


**Figure 6. Depth vs Surface Area for 200 ac-ft Hillside Reservoir**

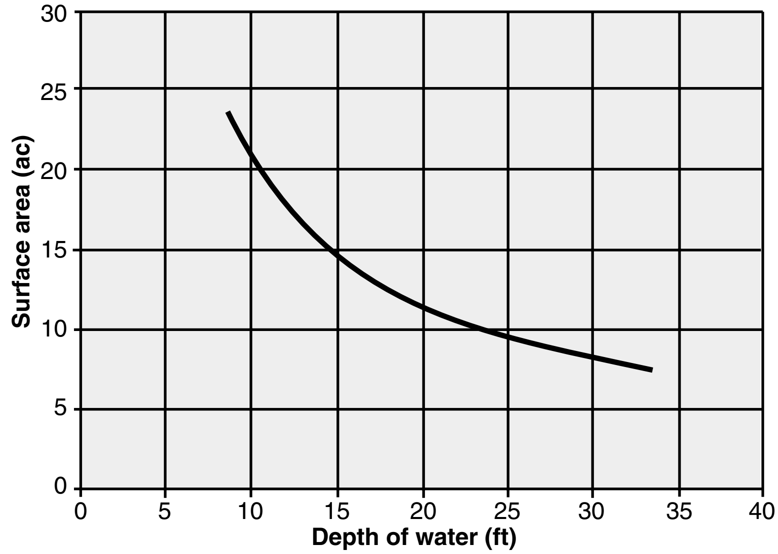



**Figure 7. Depth of Water vs Fill for 300 ac-ft Hillside Reservoir**

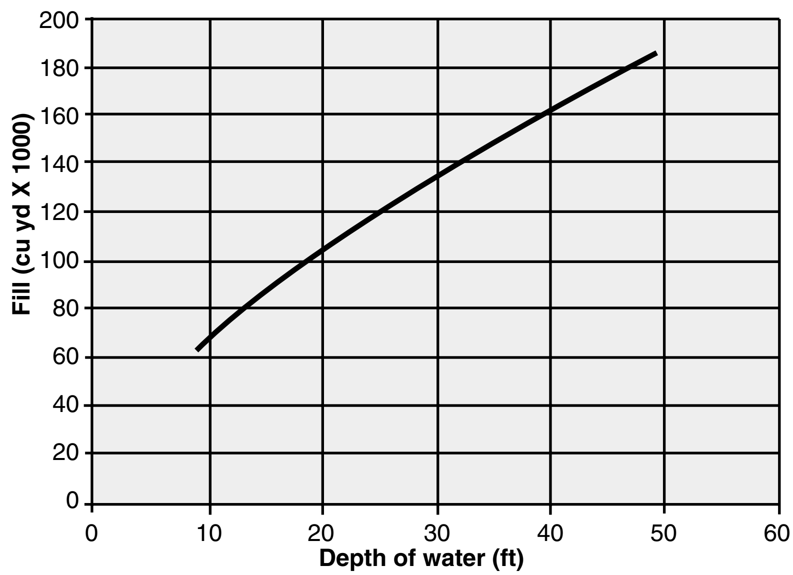



**Figure 8. Depth vs Surface Area for 300 ac-ft Hillside Reservoir**