The Economics of Stormwater BMPs in the Mid-Atlantic Region

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CENTER FOR WATERSHED PROTECTION

ABSTRACT

TITLE: The Economics of Stormwater BMPs in the Mid-Atlantic Region: Final Report

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ORGANIZATION: The Center for Watershed Protection is a national non-profit organization dedicated to helping local communities protect streams, lakes and estuaries through improved management of the land. Specifically, the Center is involved as an urban extension service to engender better watershed protection and restoration plans at the local and state level

ABSTRACT: This report presents current (1996 - 1997) cost data for urban stormwater practices, updates BMP cost prediction equations, and assesses the cost-effectiveness of the BMPs most commonly used in the Mid-Atlantic region. This examination of BMP cost includes 70 stormwater BMPs in the Mid-Atlantic area, including 38 pond systems (18 dry ED ponds, and 18 wet or wet ED ponds and two wetlands), 12 bioretention areas, nine sand filters and five infiltration trenches. In general, the study confirms earlier studies that storage volume is a reasonably strong indicator of total construction cost for urban BMPs. Accurate cost projection equations are provided for ponds, wetlands and bioretention areas. This study is intended for use by engineers, planners, and municipal officials as they consider BMPs in conjunction with watershed restoration and protection efforts, stormwater management strategies, erosion and sediment control plans, and BMP design manuals and criteria.

PRICE: $15.00 (includes shipping and handling)

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CENTER FOR WATERSHED PROTECTION

THE ECONOMICS OF STORMWATER BMPS IN THE MID-ATLANTIC REGION: FINAL REPORT

an examination of the real cost of providing stormwater control

prepared by:

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Table of Contents

Appendices

List of Tables

List of Figures

The Economics of Stormwater BMPs

Stormwater management can be the single greatest out-of-pocket cost that developers have to pay to meet local watershed protection requirements. Yet, surprisingly little is known regarding the true cost of constructing stormwater management practices. The last major study on the cost of urban stormwater management was conducted more than a decade ago by Wiegand et al. (1986) who examined the construction cost of 65 stormwater management ponds in the Washington metropolitan area.

Since then, new questions have arisen regarding the economics of stormwater best management practices (BMPs). Developers and watershed managers alike have become more interested in questions such as :

- Has the cost of constructing stormwater management facilities increased over the last decade? To what extent have new design and permitting requirements increased these costs?
- What is the cost of the "next-generation" BMPs such as sand filters, bioretention areas, stormwater wetlands, and other innovative practice? Are they cheaper to construct than ponds?
- What share of total stormwater management costs are due to water quality requirements versus stormwater detention for peak discharge control requirements?
- Do BMPs still exhibit economies of scale, i.e., is it still cheaper to construct a single large BMP than a series of smaller ones to serve the same drainage area?
- Lastly, how cost-effective are BMPs in terms of dollars per pound removed?

To address these questions, the Center for Watershed Protection initiated a study in 1996 to obtain current cost data for urban stormwater practices and to develop updated BMP cost prediction equations. The cost survey included 70 stormwater BMPs in the Mid-Atlantic area for which bond estimates, engineering estimates and actual construction contracts were available. The types of BMPs analyzed included pond systems, bioretention areas, sand filters, and infiltration practices. Cost estimates for the BMPs were provided by private engineering firms and pubic agencies operating in Maryland and Virginia. The surveyed BMPs reflects the wide range of local design criteria and stormwater permitting requirements.

I. METHODOLOGY

To collect data for the cost-effectiveness study, a survey was distributed during 1996 and 1997 to local government engineers and planners and consulting engineers within the Chesapeake Bay region. (A copy of the survey form is presented in Figure 1). Fourteen organizations supplied data for the majority of the BMPs. Additional entries were obtained through review of published BMP studies and through visits to local stormwater management departments. The survey results were compiled and entered into a computerized database to facilitate statistical analysis of the cost data.

FIGURE 1
BMP COST-EFFECTIVENESS SURVEY FORM

Cost Effectiveness Database Entry ID: 1

Project:	*Contact Name:*
Year: 1996 *City:* Emmitsburg	*Company:*
County: Frederick *State:* MD	*Address:*
Engineer:	
Builder:	*City:* *State :* MD
Drainage Area: 3.2 ac *% Impervious:* 22.5 %	*Zip:* 21727- *Phone:*

SECTION I. PURPOSE ☐ Quantity Control ☐ Quality Control ☒ Quantity and Quality Control

SECTION II. FACILITY TYPE

☒ *Stormwater Pond*
- ☐ Wet Pond
- ☒ Dry Extended Detention
- ☐ Wet Extended Detention
- ☐ Quantity Control Pond

☐ *Stormwater Wetland*
- ☐ Shallow Marsh
- ☐ Extended Detention
- ☐ Submerged Gravel
- ☐ Pocket Wetland

☐ *Open Channel Practice*
- ☐ Grass Channel
- ☐ Dry Swale
- ☐ Wet Swale
- ☐ Vegetated Filter Strip

☐ *Filtering Practice*
- ☐ Organic Filter
- ☐ Perimeter Sand Filter
- ☐ Surface Sand Filter
- ☐ Underground Sand Filter

☐ *Infiltration Practice*
- ☐ Porous Pavement
- ☐ Infiltration Trench
- ☐ Infiltration Basin

☐ *Other*

☐ *Combination*

SECTION III. DESIGN STORAGE

* Water quality storage:		ac-ft	OR	5800	cubic ft	Elevation:	393.2	feet
2 year volume:	0.33	ac-ft	OR		cubic ft	Elevation:	394.7	feet
10 year volume:	0.51	ac-ft	OR		cubic ft	Elevation:	395.9	feet
100 year volume:	0.65	ac-ft	OR		cubic ft	Elevation:	396.7	feet
** Surface area:		sq ft						

** Permanent pool and extended detention, wherever provided*

*** For bioretention, grass channels and sand filters only*

SECTION IV. COST DATA

Please provide the following cost data:

Design and Engineering:	$3,000.00
Excavation and Grading:	$8,170.00
Control Structure:	$2,334.00
Sediment Control:	$400.00
Landscaping:	
Appurtenances:	$3,360.00

SECTION V. ADDITIONAL INFORMATION

Please attach the following :

- ☒ TR-55 Worksheet #2 Post development condition.
- ☒ Plan View
- ☒ Stage-Storage Data
- ☒ Engineer's Estimate

Notes:

Total Cost: $17,264.00

Survey respondents were asked to provide both general project information and specific data related to cost and design criteria. Respondents were also asked to provide BMP drawings, stage-storage curves, engineer's estimates and TR-55 worksheets, if available. The survey results were grouped according to BMP category and type. Specific categories and types are listed in Table 1.

TABLE 1
BMP CATEGORIES AND TYPES

Category	Type	# of entries
Ponds and Wetlands		**41**
	Dry extended detention ponds	18
	Wet extended detention ponds	11
	Wet Ponds	9
	Extended detention wetlands	1
	Shallow marsh wetlands	2
Filters		**9**
	Perimeter sand filters	1
	Surface sand filters	4
	Underground sand filters	4
Bioretention practices		**11**
	Organic filters	11
Others		**12**
	Sand filter / pond combinations	2
	Underground detention options	2
	Miscellaneous	8
	Total	***73***

I.1 Development of Cost Estimates

Total cost and cost component estimates were requested in the survey, including:

Design and engineering:	costs associated with the design and engineering of the BMP;
Excavation and grading:	costs associated with excavating and grading the BMP site;
Control structure:	cost of the control structure (riser, barrels, etc.)
Sediment control:	costs associated with erosion and sediment controls used specifically at the BMP site;

Landscaping:	costs for landscaping materials and labors directly associated with the BMP; and
Appurtenances:	costs for additional items not included elsewhere, e.g., rip-rap, trash racks, etc.

Most of the cost data used in this study were based on engineer estimates. In addition, bond prices and contractor bids were used. Bond prices were obtained from local stormwater management departments. The bond prices typically represented total construction fees, a lump sum which included fees for permitting, as-built plans, supervision and administration. Contractor bids usually only reflected the "hard" costs of building the BMP and did not include soft costs such as design and engineering or permitting fees. Because of the variance in the types of costs reported, not all cost estimates were complete. These gaps were filled by using "unit rates" for various construction components based on algorithms developed from complete cost surveys. For example, for all the ponds and wetlands for which both excavation and total costs were reported, the average unit rate for excavation was computed to be 40 % of the total cost. This 40% unit rate was used to fill in missing data gaps.

I.2 Development of Storage Volume Estimates

Four storage volumes were reported in the survey: water quality volume, 2-year storm volume, 10-year storm volume, and the 100-year storm volumes. These are the typical design volumes used in the Mid-Atlantic region. The water quality volume is the stormwater quality treatment volume. The 2-year storm volume criteria is designed to protect channels from downstream erosion. The purpose of the 10-year storm volume criteria is to prevent an increase in the frequency and magnitude of out-of-bank flooding. The 100-year storm criteria is intended to prevent flood damage from infrequent but large storm events, maintain the pre-development 100-year floodplain, and protect the integrity of the control structure.

Two volumes were used to develop cost equations for predicting construction costs: the water quality volume and the 10-year storm volume. Water quality volume estimates for ponds and wetlands were based on survey responses. Water quality volumes for filters and bioretention practices were calculated based on drainage area, surface area, and imperviousness (see Table 2). For the purpose of this study, the 10-year storm volume was defined as the total volume. Total volume for ponds and wetlands was defined as the 10-year storage. This total volume is a cumulative volume, incorporating the water quality, 2-year, and 10-year volumes. Total volume was not computed for filters and bioretention practices as these BMPs provide only water quality control.

I.3 Development of Cost Equations

The BMP cost data were statistically analyzed to re-examine the relationship between storage volume and construction cost first established in the Wiegand (1986) study. Specifically, two types of construction costs were examined: base construction cost and total construction cost.

Base construction cost was defined as the sum of the excavation, control structure, and appurtenances costs. Total construction costs included the base construction cost as well as design and engineering, sediment control, and landscaping costs.

Regression equations relating construction costs and storage volumes were developed for ponds and wetlands, filters, and bioretention practices. Log-transformed costs and volumes were related using power analysis; associated correlation coefficients (r^2) were examined to determine the validity of the relationships. The specific costs and volumes examined are listed in Table 3.

TABLE 2
WATER QUALITY VOLUME ESTIMATES

BMP Category and Type	**Water Quality Volume (WQV)**
Ponds and Wetlands	
Wet extended detention pond, extended detention wetlands	Reported values used, includes extended detention and permanent pool volume.
Dry extended detention ponds	Reported values used, equal to extended detention volume.
Wet ponds, shallow marsh wetlands	Reported values used, equal to permanent pool volume.
Filters	
Perimeter, surface, and underground sand filters	Computed value based on reported drainage area and imperviousness. WQV = [drainage area (ac)]*[imperviousness]*[0.5 (ft)]
Bioretention	
Bioretention practices	Computed value based on reported surface area. WQV = ([surface area (sf)]*[0.75 (ft)])/43,560

I.4 BMP Cost-Effectiveness Database

The BMP Cost-Effectiveness Database is a dynamic computer database, consisting of 73 datasheets cataloged in Microsoft® Access (Version 2) format. Each datasheet corresponds to an individual BMP survey form. The Microsoft® Access format allows users to extract specific data, perform statistical analysis, and enter additional BMP data. The Center for Watershed Protection will maintain and update the Database as new data become available. A print-out of the Database is provided in Appendix A.

TABLE 3
COST AND VOLUME RELATIONSHIPS EXAMINED

BMP Type	Relationships Examined
All ponds and wetlands	Total volume vs. Total cost[1]
Dry extended detention ponds	Total volume vs. Base cost[2]
Wet extended detention ponds	Water quality volume vs. Total cost
Wet ponds	Water quality volume vs. Base cost
All Filters	Water quality volume vs. Total cost
Underground Filters	Water quality volume vs. Base cost
Sand Filters	
All Bioretention Practices	

1 Total construction costs included the base construction cost as well as design and engineering, sediment control, and landscaping costs.

2 Base construction cost was defined as the sum of the excavation, control structure, and appurtenances costs.

II. BMP COST - STORAGE RELATIONSHIPS

The BMP cost data were analyzed to re-examine the relationship between storage volume (in cubic feet) and construction cost first established in the Wiegand (1986) study. The results of this analysis are summarized in Tables 4, 5, and 6. The data were also used to generate plots of storage volume versus costs. These plots are presented in Appendix A.

In general, the strongest relationships between storage volume and BMP cost were exhibited by ponds and wetlands *en masse,* dry extended detention ponds, and bioretention facilities. These three groups all have relatively robust data sets (11 or more observations) and statistically significant r^2 (greater than or equal to 0.77). These strong relationships were used to develop revised cost-prediction equations and to examine changes in BMP costs and BMP cost-effectiveness.

II.1 Ponds and Wetlands

Total volume is a strong indicator of stormwater pond and wetland costs

Total volume (i.e., stormwater quantity *and* quality volume) is a reasonably strong indicator of stormwater pond and wetland costs (Table 4, Equations 4.1 and 4.2). The total volume-BMP cost equations indicate that economies of scale prevail for all ponds and wetlands (i.e., the exponents in the equations are less than one). In other words, the larger the pond or wetland, the less expensive the facility on a per cubic foot of storage basis.

In general, the weakness of the volume-cost relationships for specific types of wet stormwater facilities (e.g., wet ponds and shallow marshes) precludes the use of those equations for prediction purposes. Costs for these wet facilities can best be predicted using the general all ponds and wetlands equations (Equations 4.1 and 4.2). This is appropriate as most of the wet extended detention ponds and stormwater wetlands in the dataset have similar sizing criteria, control structures, and landscaping requirements.

It should be noted that the wet ponds used in this study included facilities with significant "ornamental" volume. Ornamental volume is defined as non-stormwater storage and includes water used for aesthetic or fishery purposes. Reported total and base construction costs included expenses associated with excavating and grading the ornamental volume.

Unlike the wet facilities data, the extensive dry extended detention pond data yielded strong predictive cost equations. Equations 4.5 and 4.6 can, therefore, be used to specifically examine dry extended detention facilities. Otherwise, the more general stormwater ponds/wetlands equations hold.

Pond and wetland costs have increased by 35 - 40% over the past decade

The updated predictive equation (Equation 4.2) was compared to the 1986 equation to gauge the change in BMP costs over time. The 1996 and 1986 total volume versus construction cost equations were applied using a 150,000 cubic foot (3.44 ac-ft) stormwater pond. Using the 1986 equation, the projected total construction cost is \$64,096 in 1996 dollars (assuming an annual inflation rate of 3%). That same pond would cost \$88,533 to construct in 1996 based on the revised equation. Comparison of these results suggests that stormwater pond and wetland costs have increased by 35 - 40% over the past decade. This comparison is represented graphically in Figure 2.

TABLE 4
COST PREDICTION EQUATIONS: PONDS AND WETLANDS

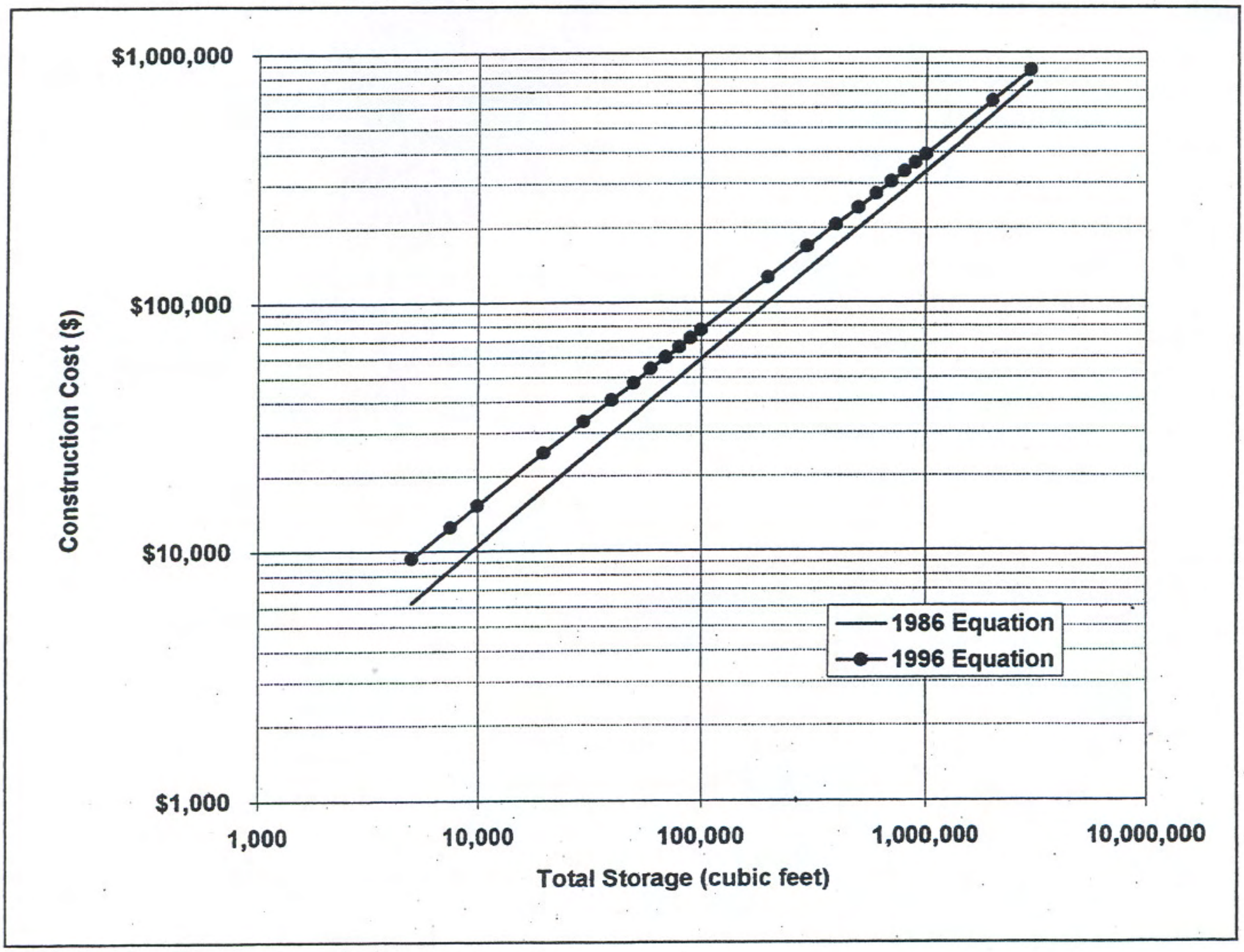
Equation	r^2	Relationship	Validity
All Ponds and Wetlands (N=41)			
(4.1) $TC = (23.07)(V_s^{0.705})$	0.80	Total volume (ft^3) vs. total cost	VALID*
(4.2) $CC = (20.80)(V_s^{0.701})$	0.77	Total volume (ft^3)vs. base cost	VALID*
$CC = (6.11)(V_s^{0.752})$	*0.80*	*Total volume (ft^3)vs. base cost (1986)*	
(4.3) $TC = (127.24)(WQV^{0.607})$	0.57	Water quality volume (ft^3) vs. total cost	
(4.4) $CC = (112.85)(WQV^{0.604})$	0.55	Water quality volume (ft^3) vs. base cost	
Dry Extended Detention Ponds (N=18)			
(4.5) $TC = (11.72)(V_s^{0.760})$	0.94	Total volume (ft^3) vs. total cost	VALID*
(4.6) $CC = (8.16)(V_s^{0.780})$	0.93	Total volume (ft^3) vs. base cost	VALID*
(4.7) $TC = (20.59)(WQV^{0.770})$	0.74	Water quality volume (ft^3) vs. total cost	
(4.8) $CC = (14.93)(WQV^{0.788})$	0.72	Water quality volume (ft^3) vs. base cost	
Wet Extended Detention Ponds (N=11)			
(4.9) $TC = (12.87)(V_s^{0.729})$	0.69	Total volume (ft^3) vs. total cost	
(4.10) $CC = (8.50)(V_s^{0.750})$	0.69	Total volume (ft^3) vs. base cost	
(4.11) $TC = (95.66)(WQV^{0.603})$	0.61	Water quality volume (ft^3) vs. total cost	
(4.12) $CC = (74.64)(WQV^{0.611})$	0.59	Water quality volume (ft^3) vs. base cost	
Wet Ponds (N=9)			
(4.13) $TC = (106.07)(V_s^{0.615})$	0.55	Total volume (ft^3) vs. total cost	
(4.14) $CC = (196.43)(V_s^{0.553})$	0.50	Total volume (ft^3) vs. base cost	
$CC = (33.99)(V_s^{0.644})$	*0.76*	*Total volume (ft^3) vs. base cost (1986)*	

* VALID denotes a strong relationship based on number of data points and r^2 value.

Water quality comprise 34 - 37% of the total construction cost of most stormwater ponds

The pond and wetland cost data were examined to determine the relative impact of water quality storage on total construction cost. Stormwater detention storage (i.e., 2-year and 10-year storm volumes) still represents the majority of total pond storage, and hence pond costs. In that same vein, the water quality storage was determined to comprise only 34 - 37% of the total pond volume on average, hence approximately one-third of the cost of most stormwater ponds and wetlands.

FIGURE 2
COMPARISON OF 1986 AND 1996 PREDICTIVE EQUATIONS



II.2 Filtering Practices

Water quality volume may be an indicator of stormwater filter costs

The survey data were used to compute the average cost of sand filters. The cost per cubic foot of storage ranged from \$2 - \$6, with an average cost of \$2.47 per cubic foot of quality storage. It was not possible to define a valid predictive relationship between sand filter costs and water quality volume, as indicated by the poor r^2 values presented in Table 5. This may be due in part to the limited number of available data.

TABLE 5
COST PREDICTION EQUATIONS: SAND FILTERS

Equation	r^2	Relationship	Validity
All Filters (N=9)			
(5.1) $TC = (156.67)(WQV^{0.571})$	0.30	Water quality volume (ft^3) vs. total cost	Not valid
(5.2) $CC = (31.82)(WQV^{0.717})$	0.41	Water quality volume (ft^3) vs. base cost	Not valid

II.3 Bioretention Practices

Water quality volume is a strong indicator of bioretention costs

Bioretention practices are now more frequently used to treat stormwater runoff. The cost survey data clearly showved that bioretention cost could be reliably predicted using water quality volume (Table 6). In fact, bioretention practices exhibited the strongest relationship between water quality volume and cost. Because the exponents in both bioretention equations are essentially equal to one, no economies of scale are evident. This is consistent with the fact that bioretention facilities are sized as a flat percentage of site area. Another way of expressing the cost of bioretention is that these practices generally cost about \$6.40 per cubic foot of quality treatment.

TABLE 6
COST PREDICTION EQUATIONS : BIORETENTION PRACTICES

Equation	r^2	Relationship	Validity
All Bioretention Practices (N=11)			
(6.1) $TC = (6.88)(WQV^{0.991})$	0.96	Water quality volume (ft^3) vs. total cost	Valid
(6.2) $CC = (5.67)(WQV^{0.990})$	0.92	Water quality volume (ft^3) vs. base cost	Valid

II.4 Infiltration Practices

Enhanced feactures have increased the cost of infiltration trenches

Since data was availble for only five infiltration trenches, no attempt was made to derive a cost equation. Instead, the data were used to verify the validity of the 1986 infiltration cost equation. This testing indicated that the older cost equation was no longer valid as it consistently underestimated costs by a factor of two or more. The higher costs for infiltration trenches appear to be due greater pretreatment measures and other enhanced design features that are now more widely used (e.g., observation wells, sand layers, etc.). Overall, the average construction cost for infiltration trenches ranged from $2 to $4 per cubic foot of water quality storage, with a mean of $2.80 per cubic foot, exclusive of design and geotechnical costs.

III. BMP COST-EFFECTIVENESS

To gain perspective on the comparative cost-effectiveness of various types of BMPs, the predictive equations were applied to two typical development scenarios: a five-acre commercial mini-mall and a fifty-acre residential subdivision. Total BMP costs were calculated for a representative stormwater pond and a bioretention facility. Two nutrients were examined: total phosphorus and total nitrogen. The computations are summarized in Tables 7 and 8.

As shown in Table 8, the total construction cost for a stormwater pond serving a five-acre commercial site is estimated to be $34,787, of which roughly a third ($12,871) is due to water quality control requirements. This facility will remove approximately 115 pounds of phosphorus over its 25-year design life. Therefore, on a cost per pound phosphorus removed basis, the stormwater pond cost-effectiveness is $112 per pound phosphorus removed.

TABLE 7
COMPARATIVE COST-EFFECTIVENESS OF STORMWATER MANAGEMENT BMPS
FIVE-ACRE COMMERCIAL DEVELOPMENT

Description	Pond	Bioretention Practice
Required water quality storage	0.264 ac-ft[1]	0.159 ac-ft[2]
Required detention storage	0.740 ac-ft	N/A
Total cost (Water quality cost)	$34,787 ($12,871)[3]	$44,109[4]
Annual phosphorus load[5]	9.8 lbs	9.8 lbs
Phosphorus removal (25 years)[6]	115 lbs	123 lbs
Cost per pound removed[8]	$112/lb phosphorus	$360/lb phosphorus
Annual nitrogen load[5]	65 lbs	65 lbs
Nitrogen removal (25 years)[5]	488 lbs	813 lbs
Cost per pound removed[8]	$26/lb nitrogen	$54/lb nitrogen

1 as computed using 90% rule (Schueler 1996)
2 computed as shown in Table 2
3 total cost computed using Equation 4.1
4 total cost computed using Equation 6.1
5 as computed by Simple Method
6 assuming pond and bioretention phosphorus removal of 47% and 50% respectively, over a 25-year period
7 assuming pond and bioretention nitrogen removal of 30% and 50% respectively, over a 25-year period
8 total water quality cost divided by 25 year design life

Comparatively, the bioretention facility removes approximately as much phosphorus as the pond, 123 pounds. The comparative removal rate, however, is offset by the high cost of the bioretention facility, estimated to be $44,109. Further, no quantity control (i.e. 2-year and 10-year-volume) is provided; bioretention facilities only provide water quality control. Consequently, bioretention is significantly less cost-effective at $360 per pound phosphorus removed, three times the stormwater pond rate.

On a dollar per pound basis, therefore, ponds appear to be the most cost-effective BMP. However, cost-effectiveness is not the sole consideration. The surface area consumed by the BMP is also an important factor, particularly at commercial sites. Approximately 4-6% of the site area must be set aside for a stormwater pond. On the other hand, the bioretention facility can easily be divided into a series of smaller facilities distributed throughout a parking lot.

TABLE 8
COST-EFFECTIVENESS OF STORMWATER PONDS
TWENTY-FIVE ACRE RESIDENTIAL SUBDIVISION

Description	Computations
Required water quality storage	1.41 ac-ft
Required detention storage	3.25 ac-ft
Total cost (Water quality cost)	$98,738 ($36,533) [1]
Annual phosphorus load [2]	9.8 lbs
Phosphorus removal (25 years) [3]	431 lbs
Cost per pound removed	$84/lb phosphorus [5]
Annual nitrogen load [2]	65 lbs
Nitrogen removal (25 years) [4]	1,815 lbs
Cost per pound removed	$20/lb nitrogen [5]

1 total cost computed using Equation 4.1
2 as computed by Simple Method
3 assuming pond phosphorus removal of 47% over a 25-year period
4 assuming pond nitrogen removal of 30% over a 25-year period
5 total water quality cost divided by 25 year design life

A similar series of computations was conducted for the second scenario, the twenty-five-acre residential subdivision. In this example, only ponds were examined as bioretention facilities are an ultra-urban BMP and not recommended for residential areas. The phosphorus and nitrogen cost-effectiveness rates were $84 per pound phosphorus removed and $20 per pound nitrogen removed. These values are approximately 30% lower than those of the pond at the smaller commercial site, reinforcing the earlier conclusion that cost-efficiency increases with facility size.

IV. Implications

The study results suggest that the cost of providing stormwater control has increased over the past decade. It appears that this increase is due, in part, additional permitting fees, landscaping, and contingencies. For a typical stormwater pond, the sum of all costs related to design, permitting, geotechnical testing, landscaping, contingencies and ESC control is equivalent to 32% of the base construction cost (Table 9). If wetlands or streams are situated near a proposed pond site, these costs escalate by 15 - 37% of the base pond construction cost. A decade ago, these factors were more on the order of 25% of base construction costs. The survey results indicate that design cost increases can be attributed to longer plan review times: seven months on average, from plan submittal to final plan approval and even longer if wetland permits are involved. Other factors reportedly driving up costs were multiple and conflicting agency reviews and changes in local design criteria and submittal requirements.

Table 9
Typical Design and Engineering Costs for Stormwater BMPs

Rule of Thumb Estimates of Typical BMP Design and Engineering Costs	% of Construction Cost
Engineering design Engineering design, wetlands present	*6* *10*
Permitting process, standard Permitting process,wetlands present	*3* *4*
Geotechnical investigations	*4*
Structural design	*3*
Erosion and sediment control for BMP	*5*
Landscaping	*4*
Contingency/unknown costs	*7*
Total additional costs *Total additional cost, wetlands present*	*32* *37*
Total additional cost (1986)	*25*

Finally, some additional costs can be attributed to advances in BMP designs. Although BMP construction costs were generally less expensive a decade ago, BMPs were also usually less effective. In comparison to current sizing criteria, BMPs designed a decade ago are undersized, and, therefore, operating at less than optimal removal efficiency. Incorporation of wetland and pre-treatment components was also rare in the 1970s and early 1980s.

It is true that the more stringent design criteria have led to a modest increase in costs. More importantly for stormwater managers, however, is recognizing the improved performance of BMP standards such as stormwater ponds and wetlands and the development of new, innovative facilities such as bioretention practices for ultra-urban areas. The increased and continued use of these more effective BMPs will enable stormwater managers to more effectively implement nutrient reduction goals and to continue to reduce pollutant loadings receiving waters such as the Chesapeake Bay and other estuaries and waters of concern throughout the Mid-Atlantic region.

References

Brown, W and T. Schueler. *BMP Pollutant Removal Database: Draft Report.* Prepared for Chesapeake Research Consortium. Center for Watershed Protection. Silver Spring, MD 208 pp.

Schueler, T. 1996. *Irreducible pollutant concentrations discharged from Urban BMPs*. Technical Note 75. Watershed Protection Techniques. 2(2): 369-371.

Tull, L. 1990. *Cost of Sedimentation/Filtration Basins*. City of Austin, TX. Unpublished data.

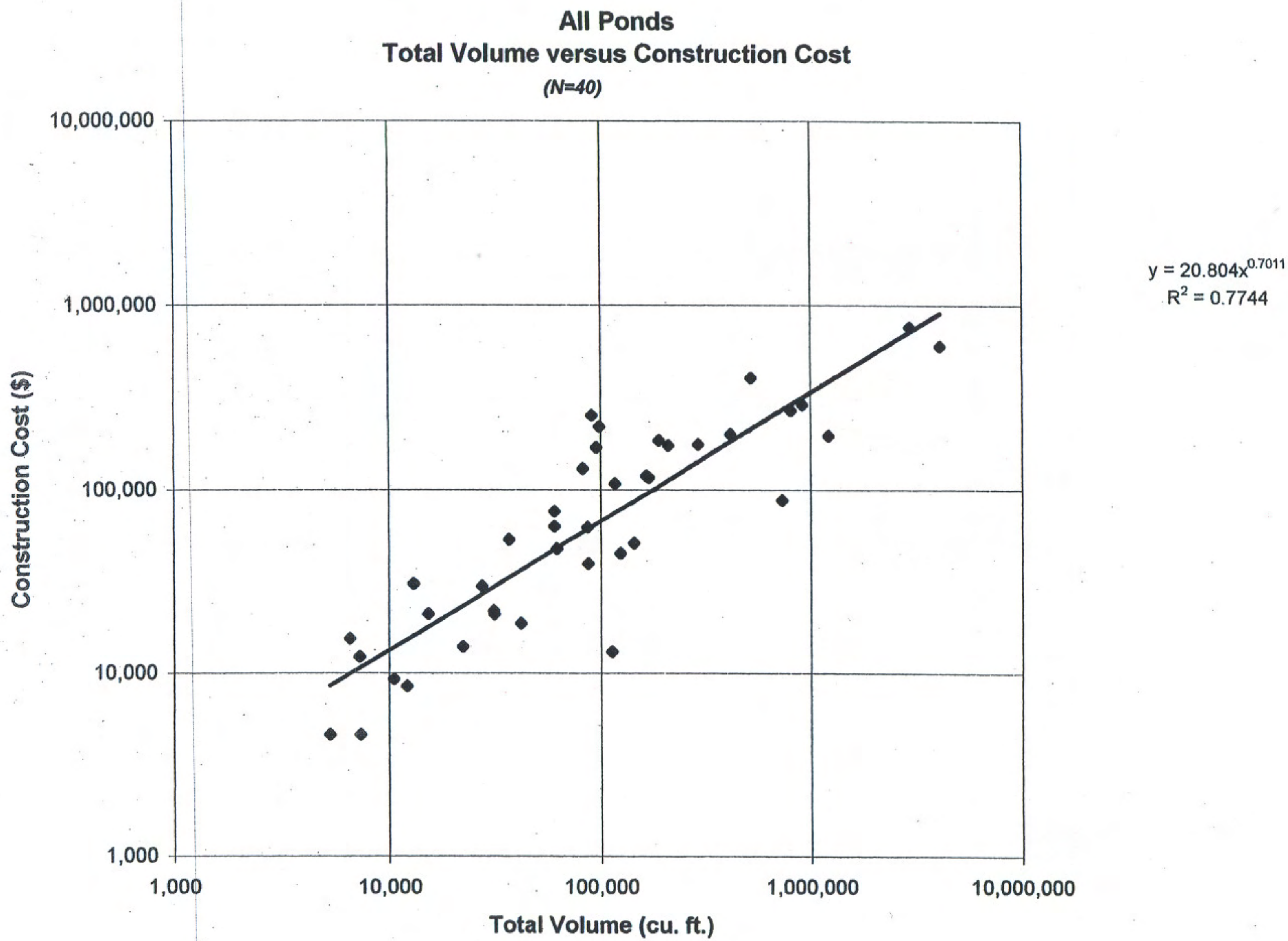
Wiegand, C, T. Schueler, W. Chittenden and D. Jellick. 1986. *Cost of Urban Runoff Controls*. In Proceedings of an Engineering Foundation Conference. Urban Water Resources. ASCE. Henniker, NH June 23-27, 1986. pp. 366-380

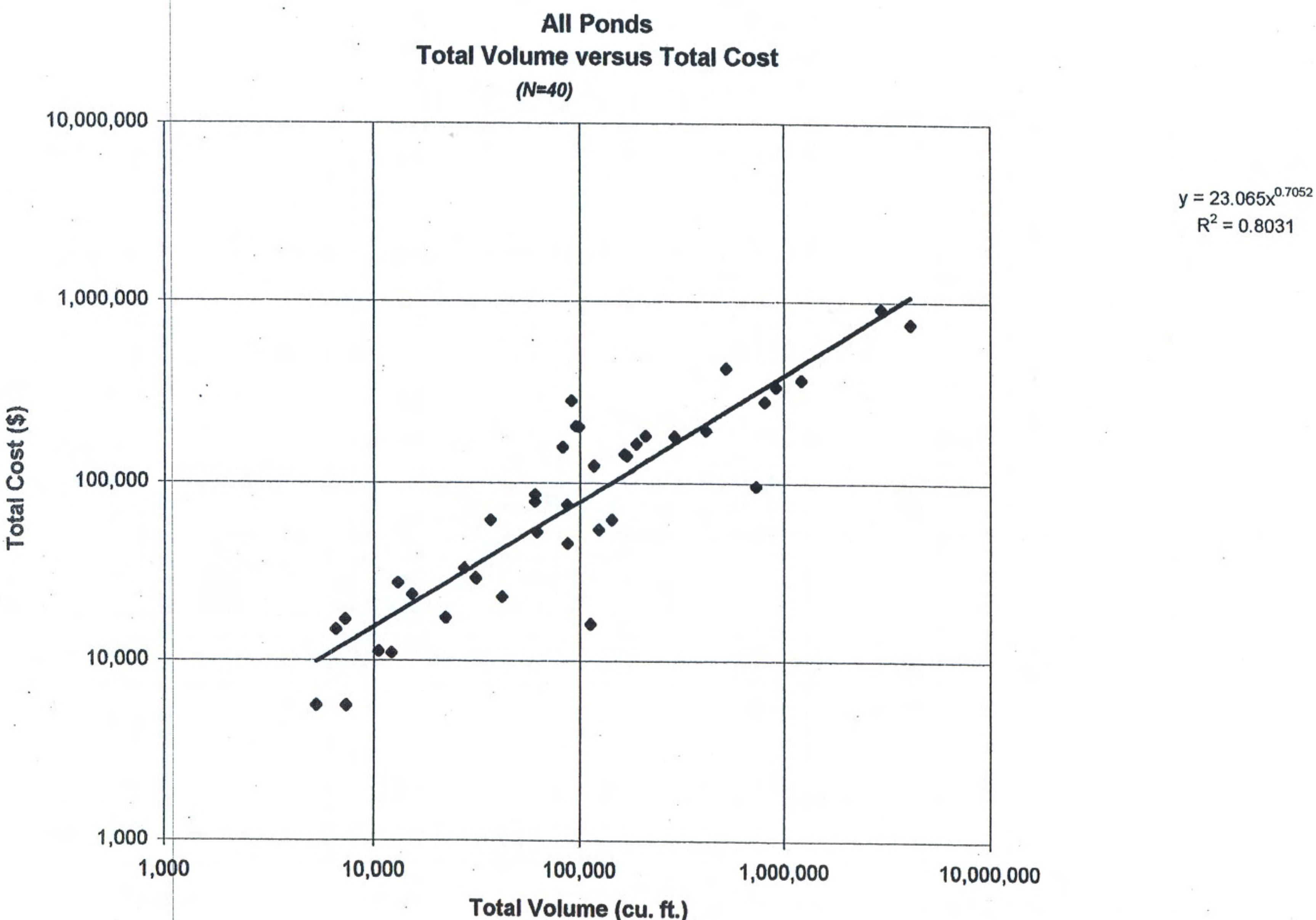
Appendix A

BMP Cost-Effectiveness Database (under separate cover)

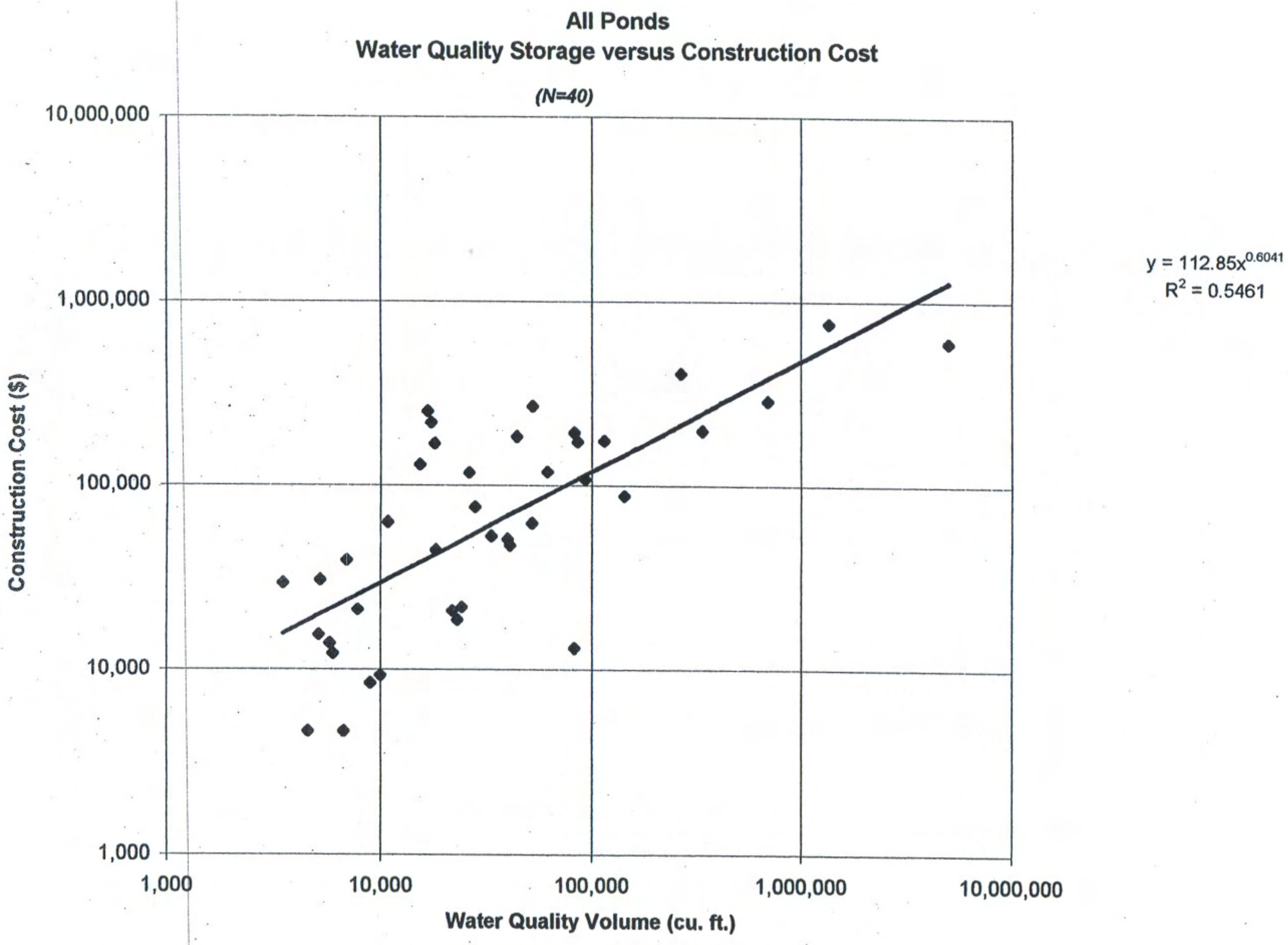
Appendix B

BMP Cost Prediction Plots

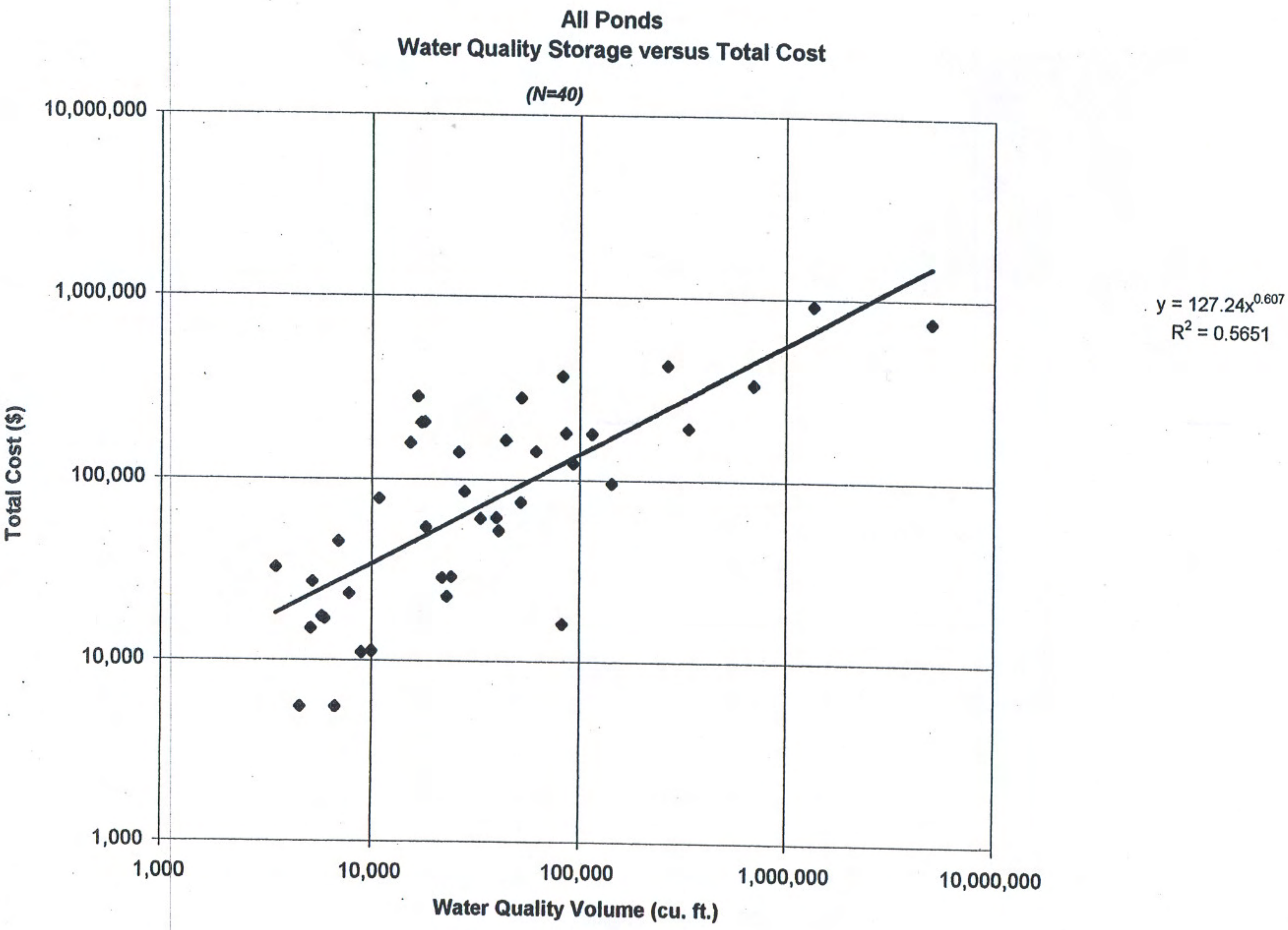

All Ponds
Total Volume versus Construction Cost
(N=40)
10,000,000
1,000,000
100,000
10,000
1,000
Construction Cost ($)
1,000
10,000
100,000
1,000,000
10,000,000
Total Volume (cu. ft.)
y = 20.804x^0.7011
R^2 = 0.7744

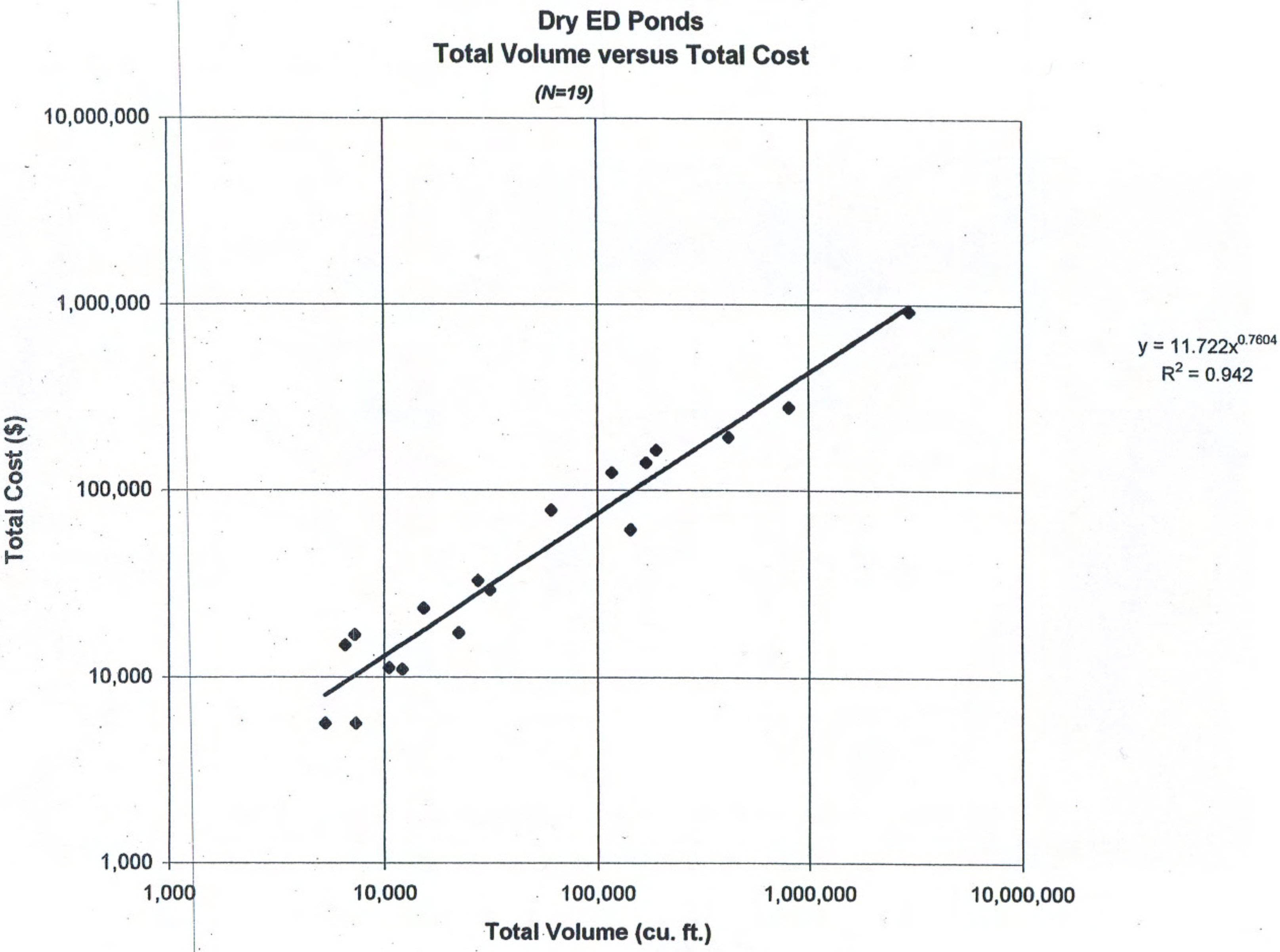


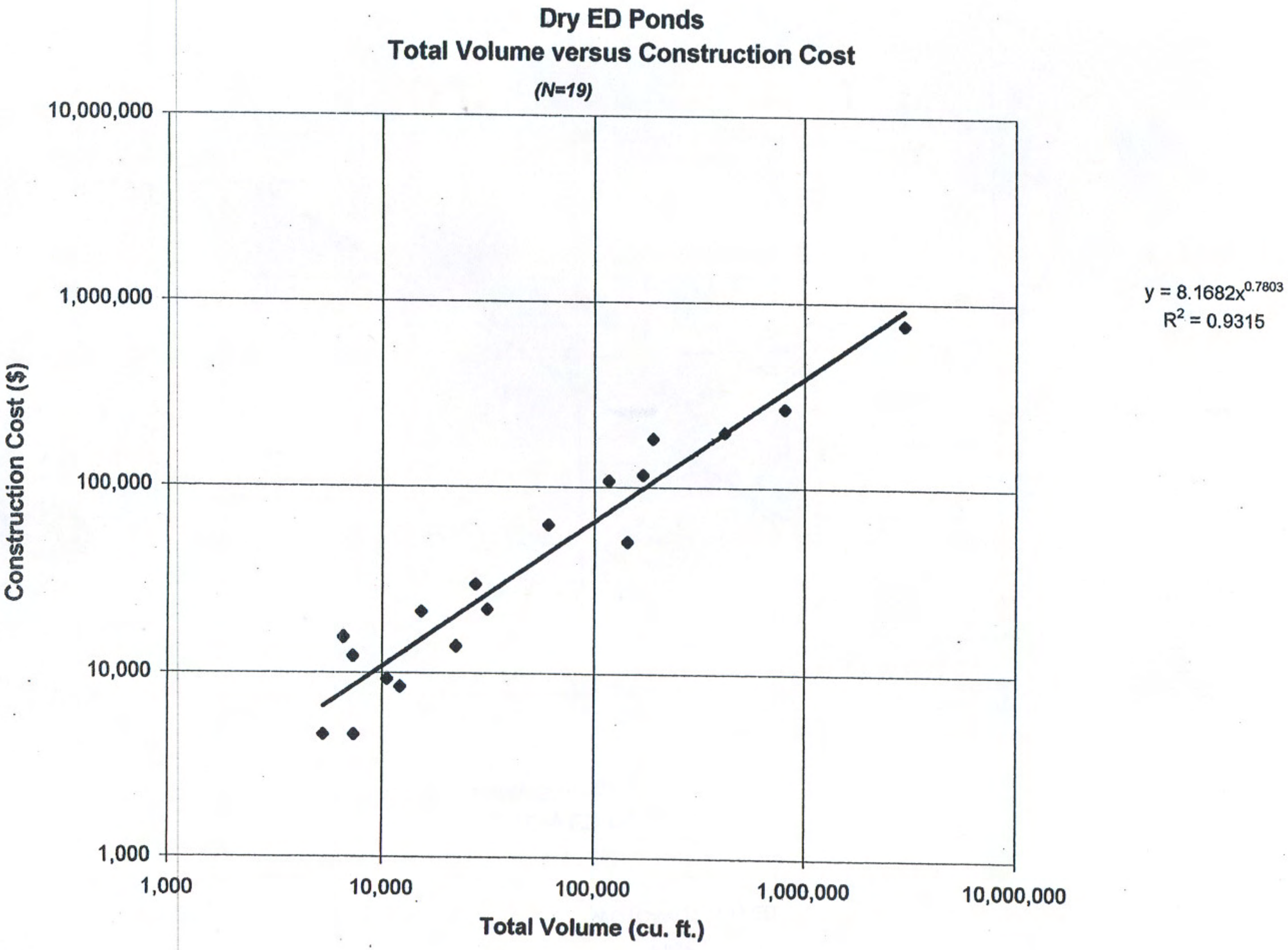
All Ponds
Total Volume versus Total Cost
(N=40)
10,000,000
1,000,000
100,000
10,000
1,000
Total Cost ($)
1,000
10,000
100,000
1,000,000
10,000,000
Total Volume (cu. ft.)
y = 23.065x^0.7052
R^2 = 0.8031

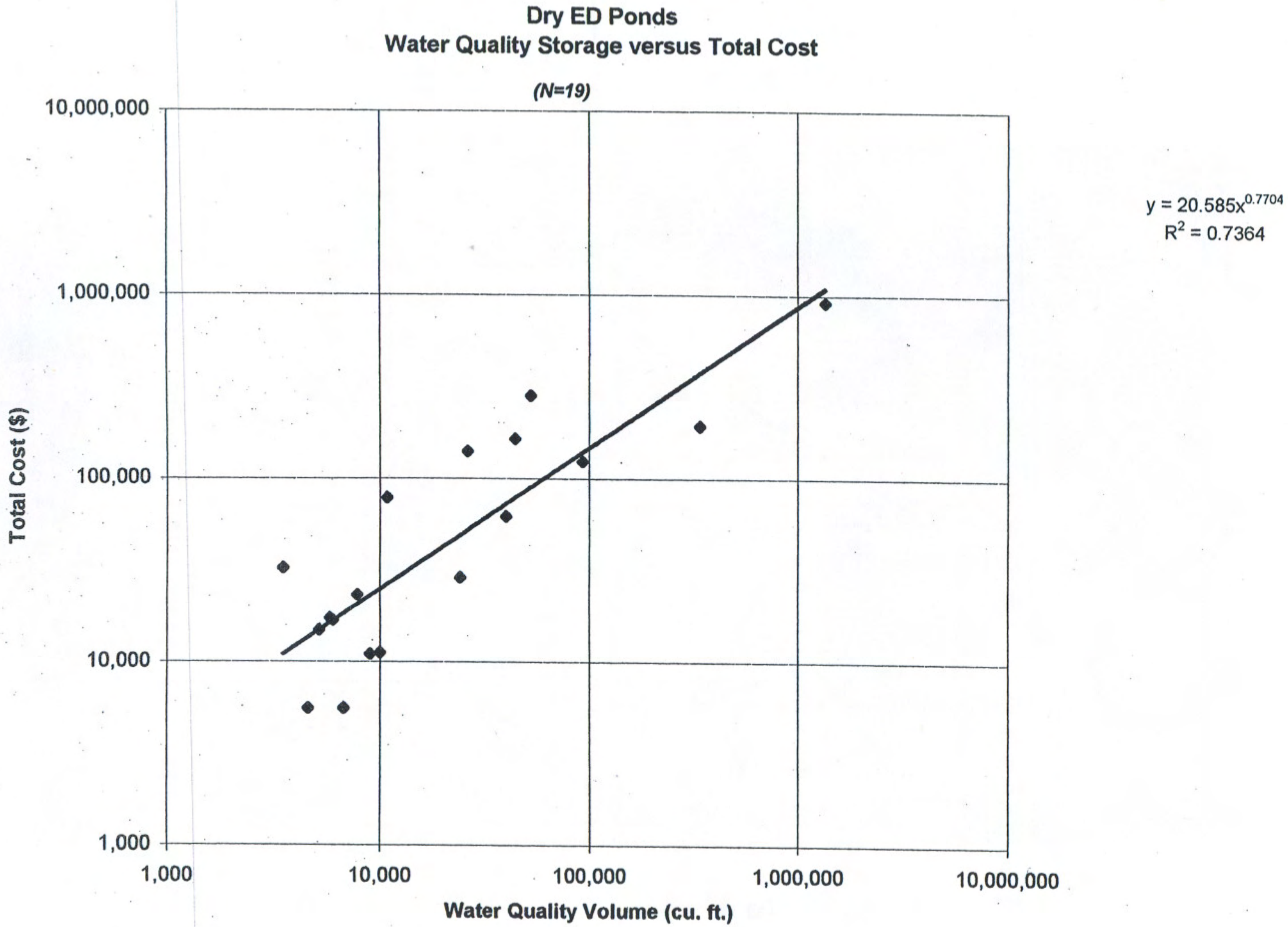

All Ponds
Water Quality Storage versus Construction Cost
(N=40)
10,000,000
1,000,000
100,000
10,000
1,000
Construction Cost ($)
1,000
10,000
100,000
1,000,000
10,000,000
Water Quality Volume (cu. ft.)
y = 112.85x^0.6041
R^2 = 0.5461

WQV-Total$, All Ponds

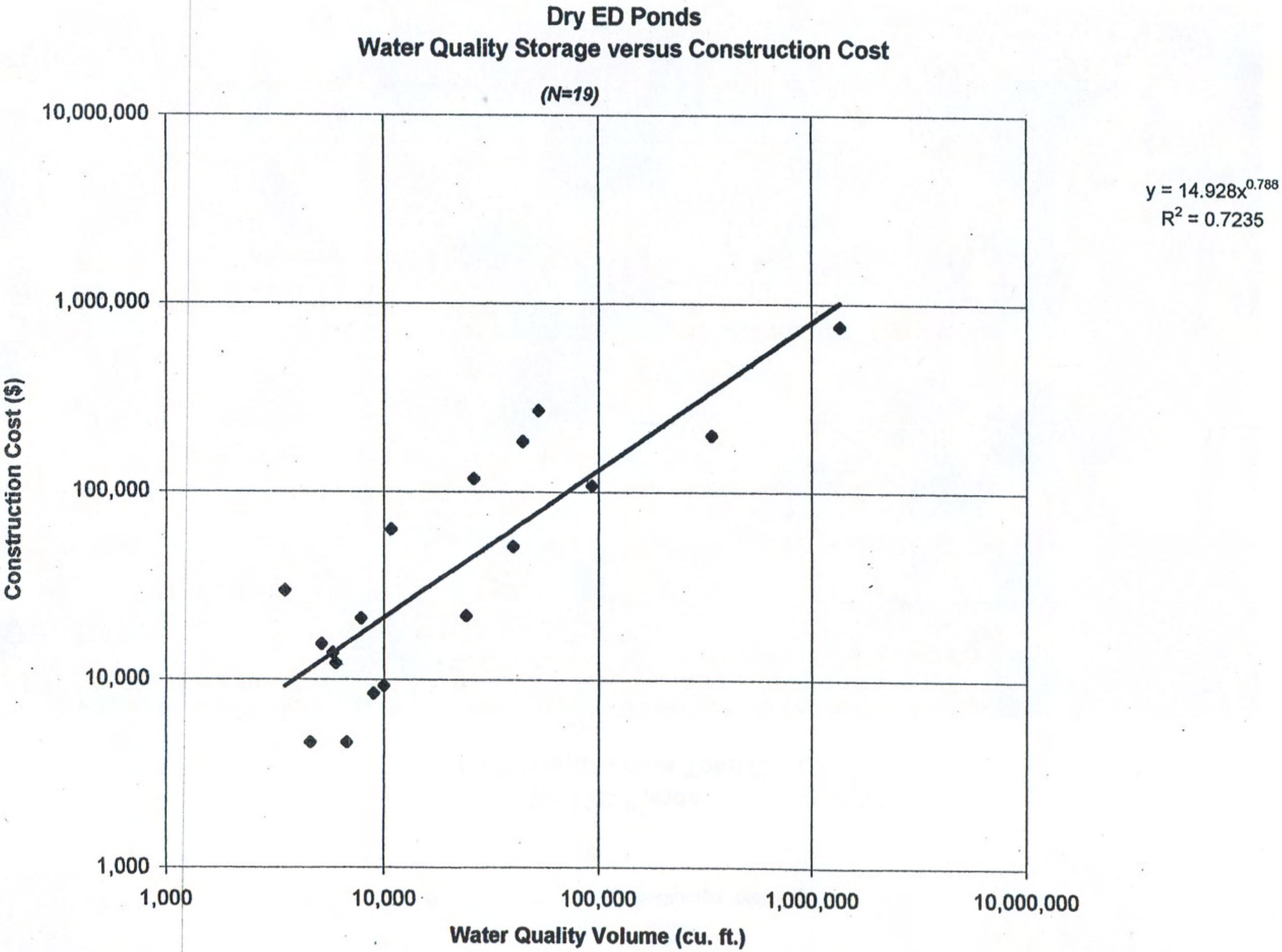


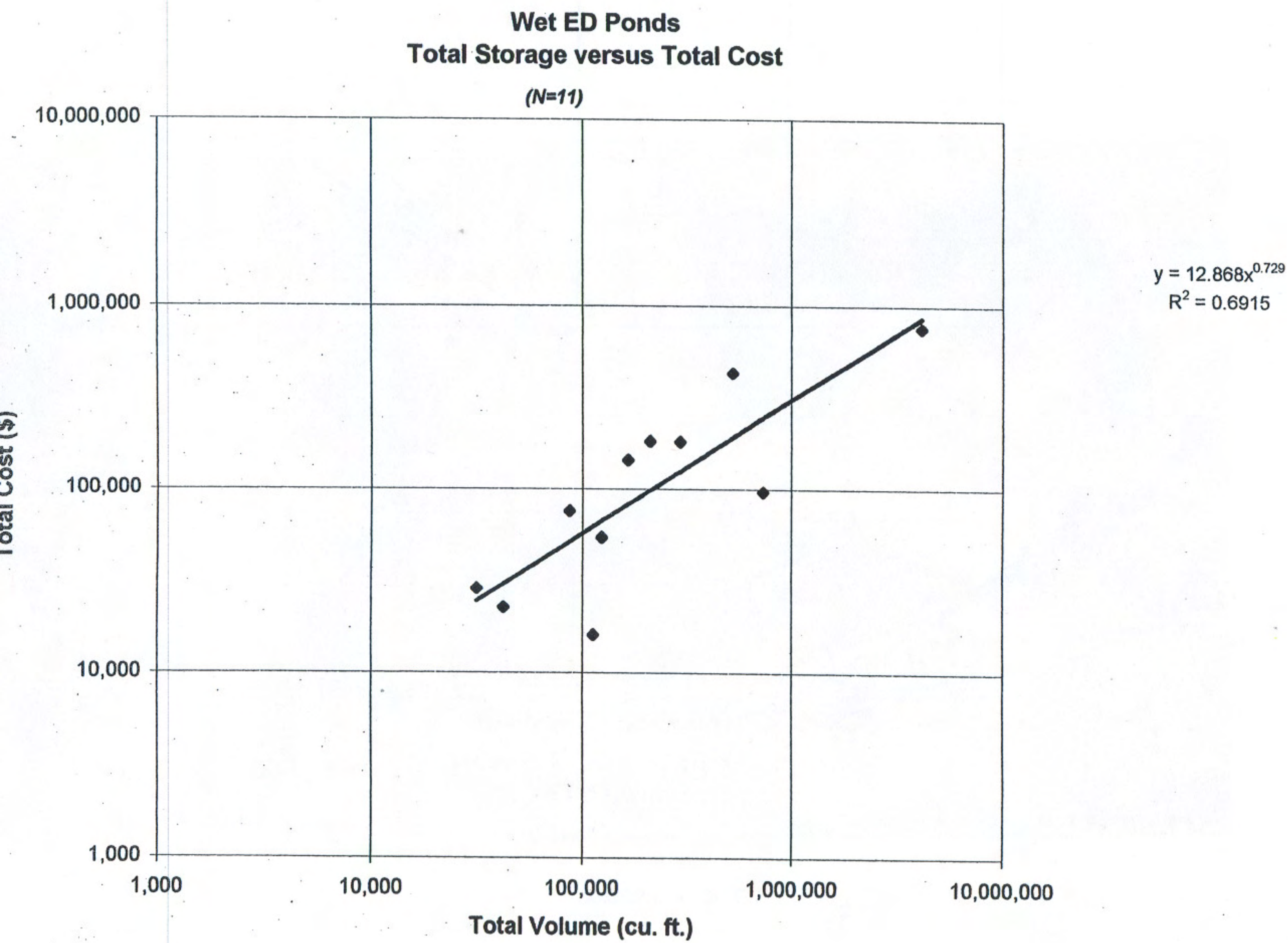

Dry ED Ponds
Total Volume versus Total Cost
(N=19)
10,000,000
1,000,000
100,000
10,000
1,000
Total Cost ($)
1,000
10,000
100,000
1,000,000
10,000,000
Total Volume (cu. ft.)
y = 11.722x^0.7604
R^2 = 0.942

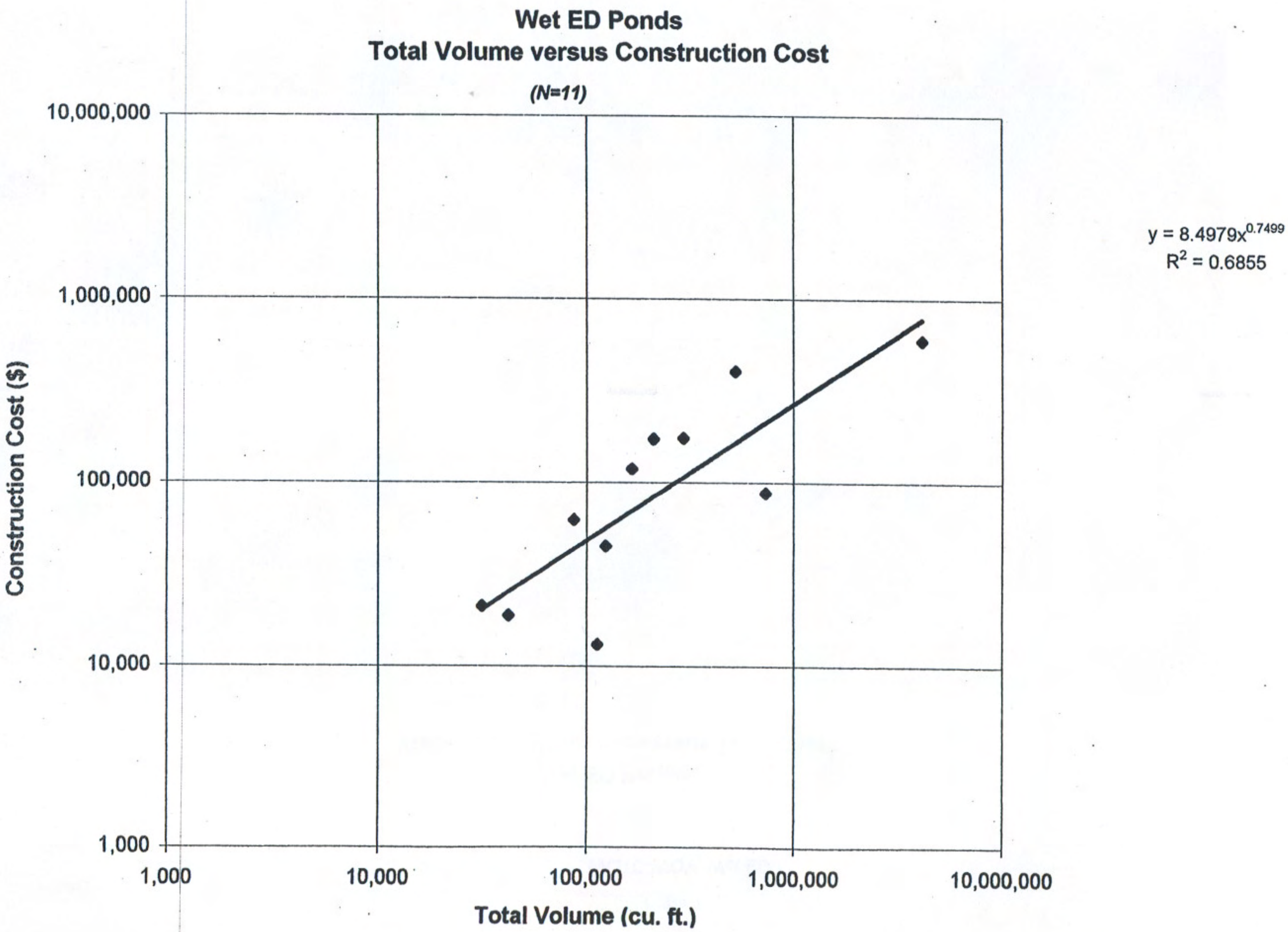

Dry ED Ponds
Total Volume versus Construction Cost
(N=19)
10,000,000
1,000,000
100,000
10,000
1,000
Construction Cost ($)
1,000
10,000
100,000
1,000,000
10,000,000
Total Volume (cu. ft.)
y = 8.1682x^0.7803
R^2 = 0.9315

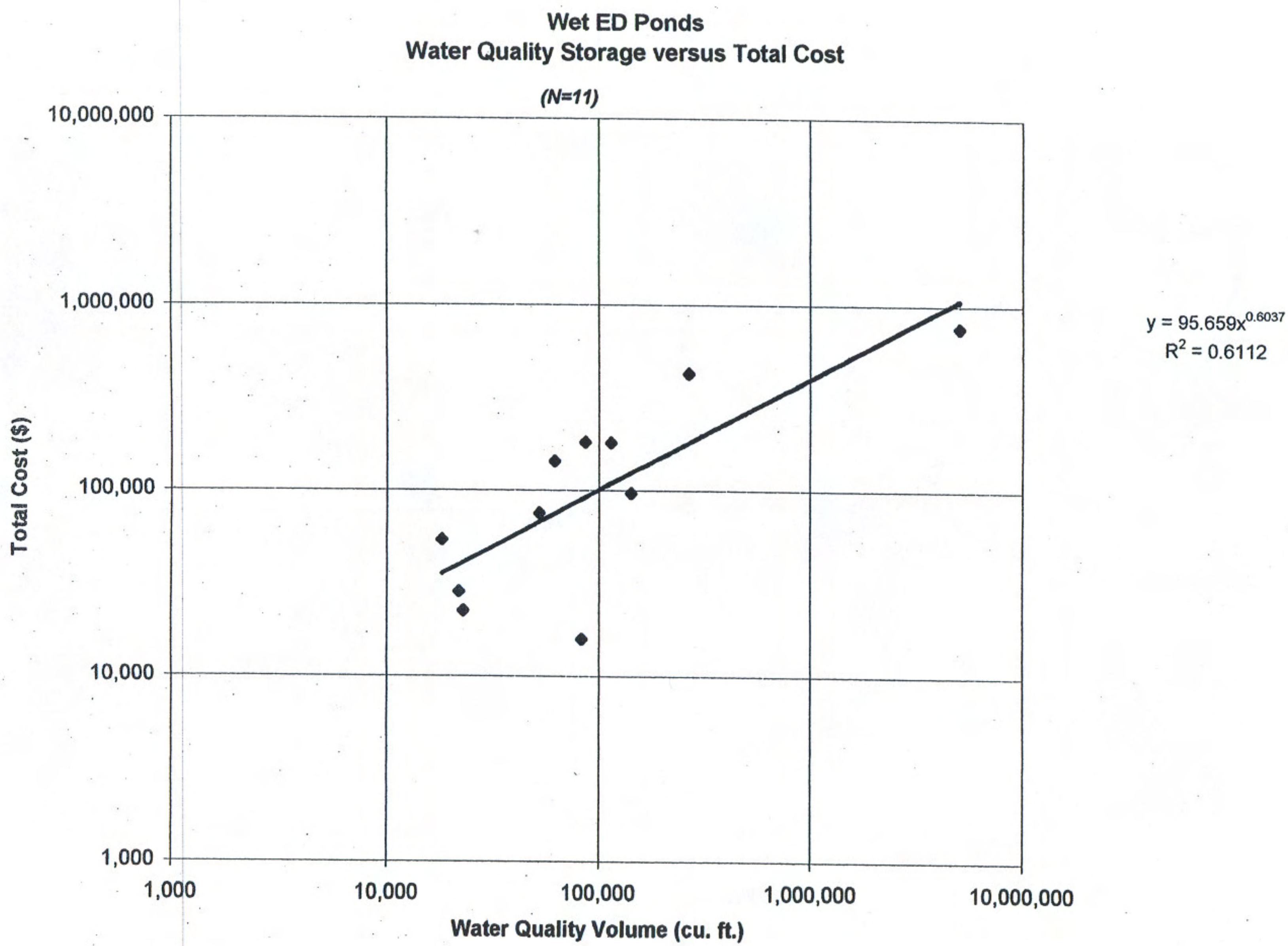

Dry ED Ponds
Water Quality Storage versus Total Cost
(N=19)
10,000,000
1,000,000
100,000
10,000
1,000
Total Cost ($)
1,000
10,000
100,000
1,000,000
10,000,000
Water Quality Volume (cu. ft.)
y = 20.585x^0.7704
R^2 = 0.7364

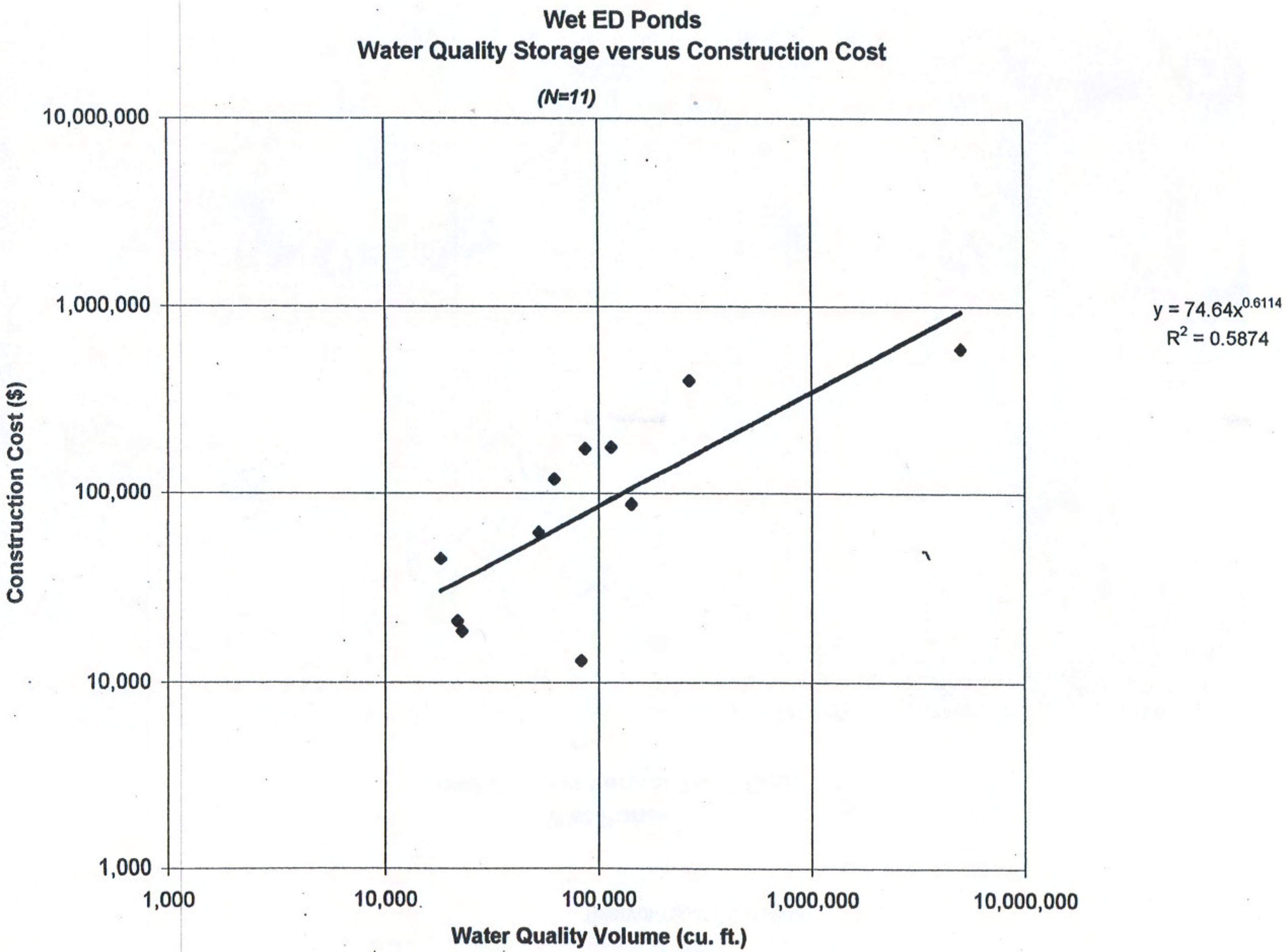
WQCC-WQV, Dry ED

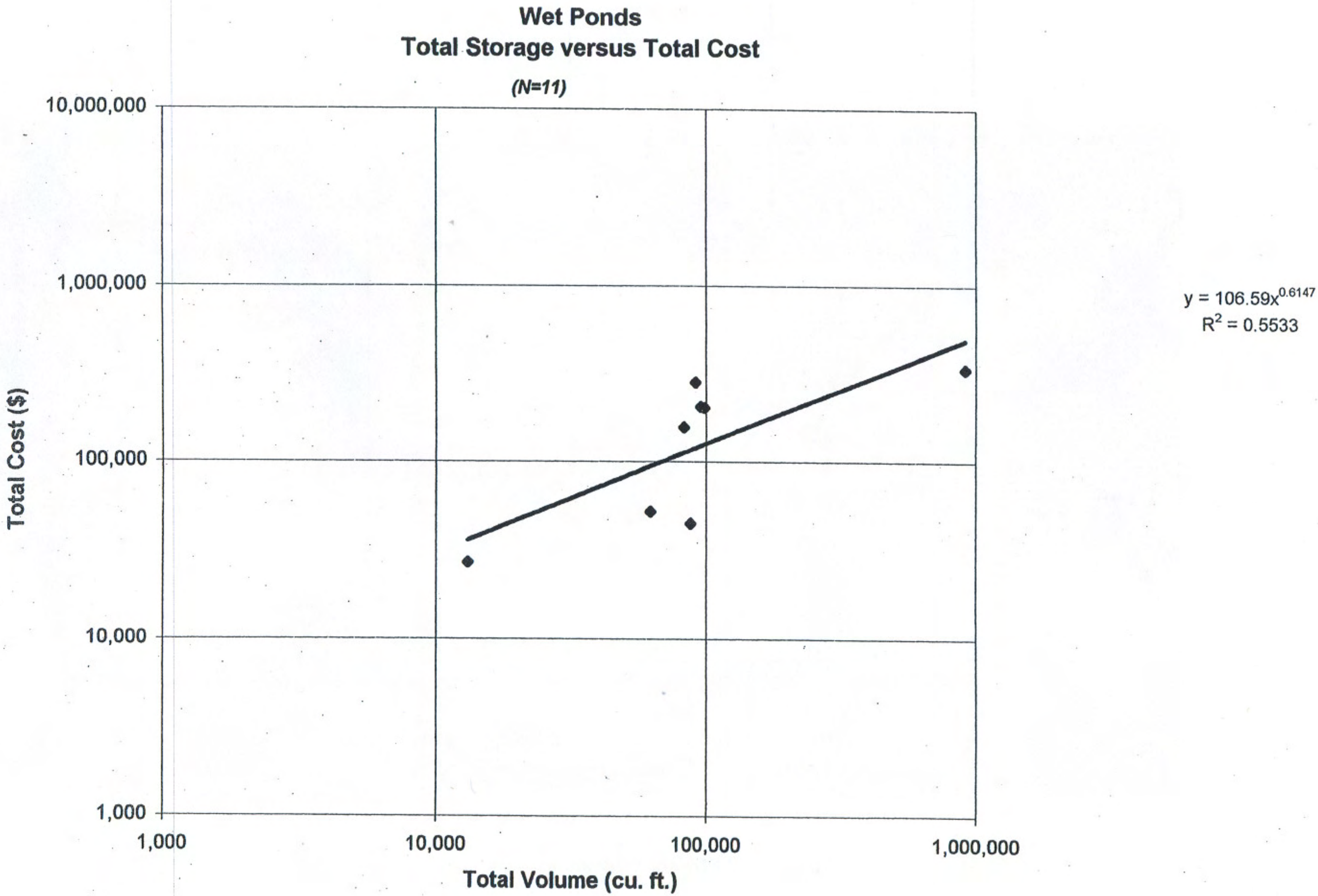


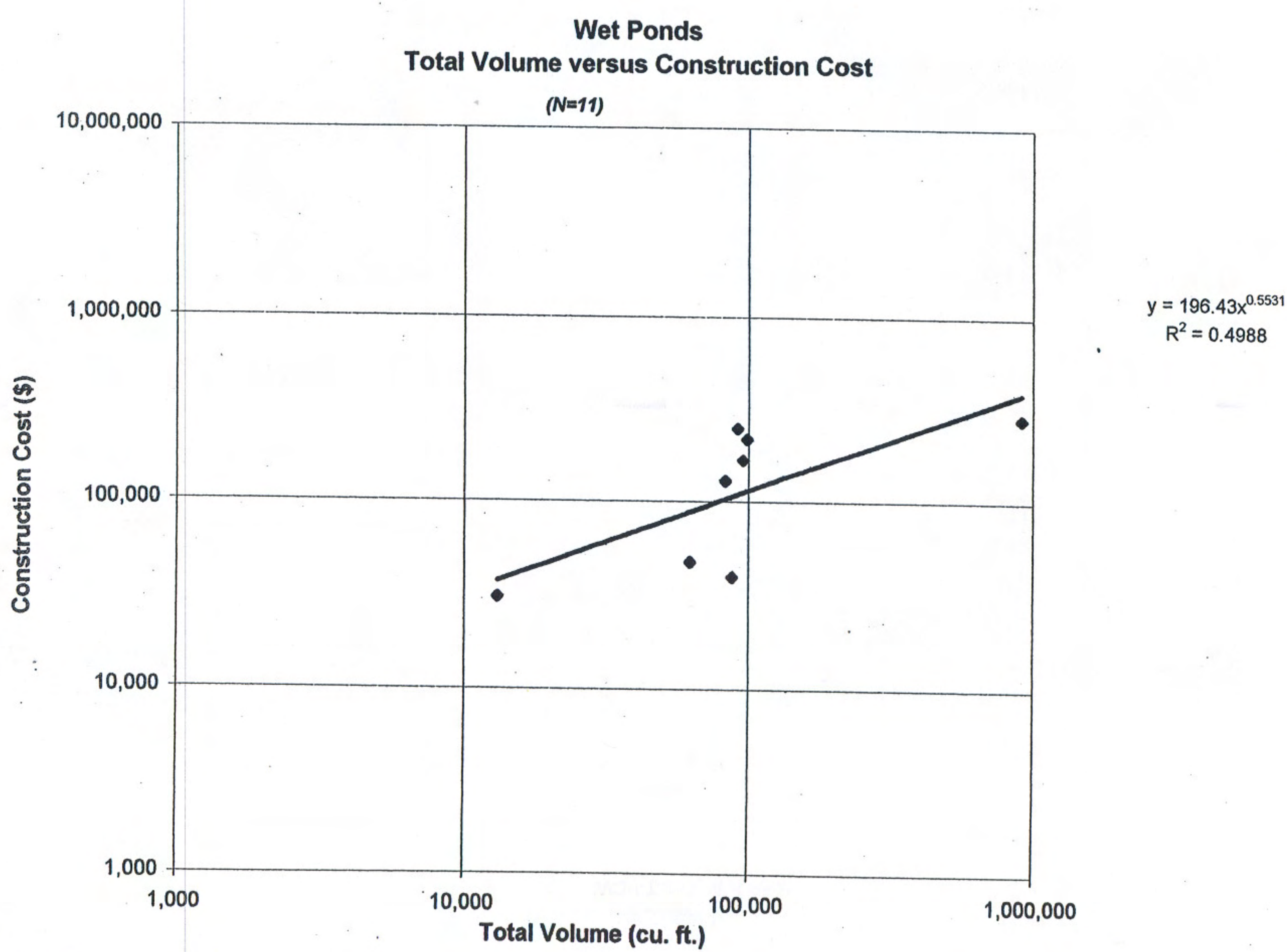

Wet ED Ponds
Total Storage versus Total Cost
(N=11)
10,000,000
1,000,000
100,000
10,000
1,000
Total Cost ($)
1,000
10,000
100,000
1,000,000
10,000,000
Total Volume (cu. ft.)
y = 12.868x^0.729
R^2 = 0.6915

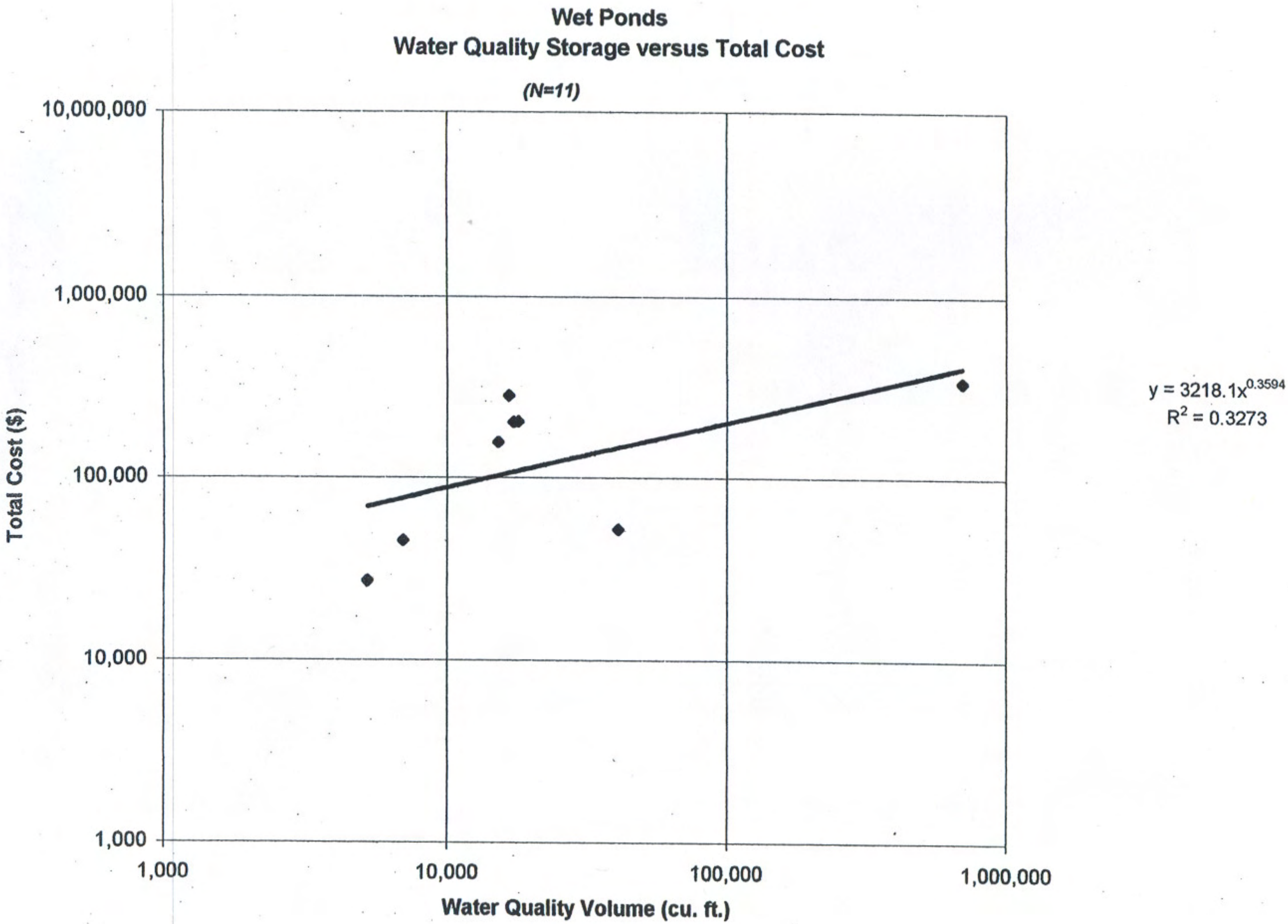

Wet ED Ponds
Total Volume versus Construction Cost
(N=11)
10,000,000
1,000,000
100,000
10,000
1,000
Construction Cost ($)
1,000
10,000
100,000
1,000,000
10,000,000
Total Volume (cu. ft.)
y = 8.4979x^0.7499
R^2 = 0.6855

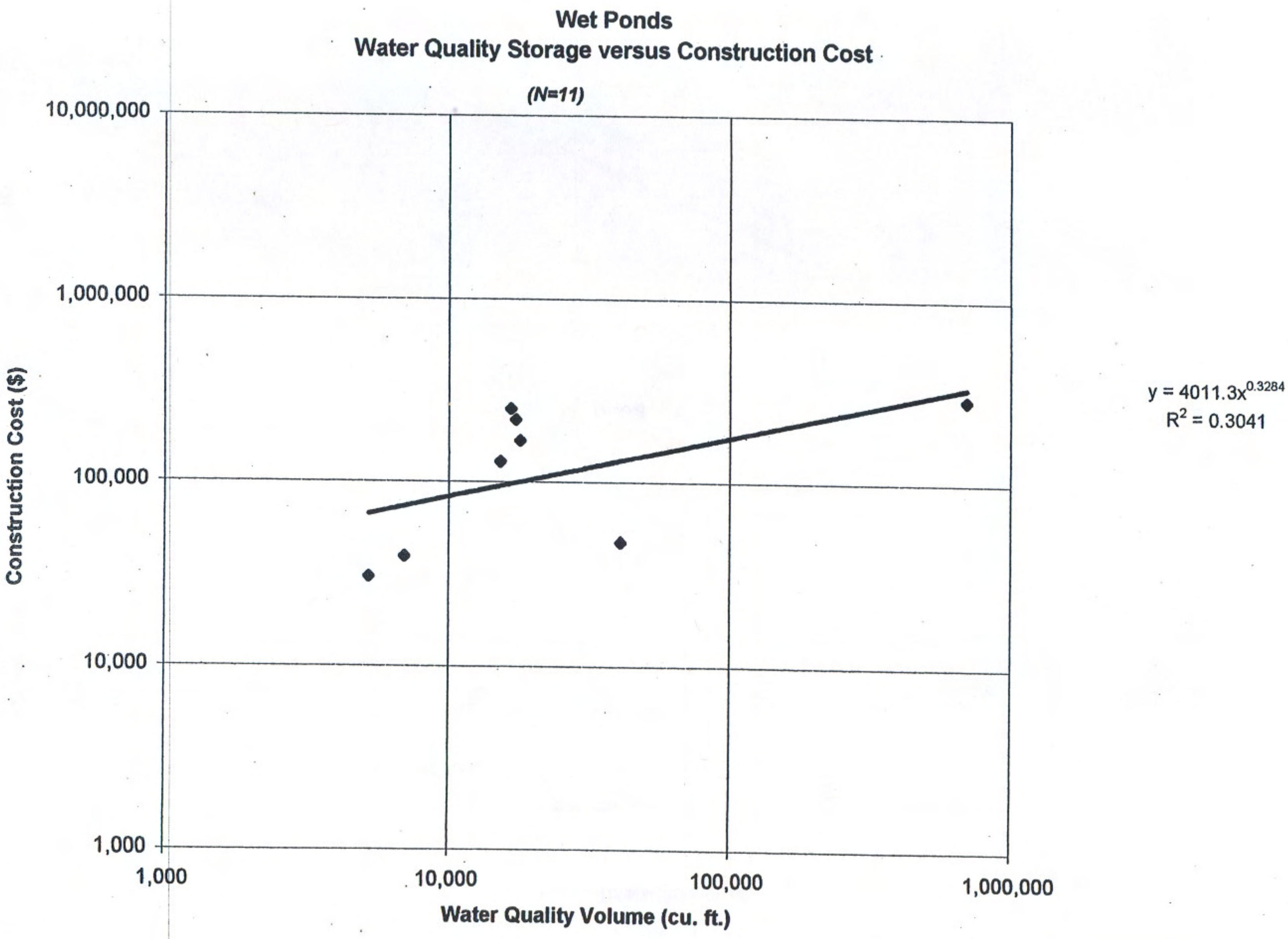

Wet ED Ponds
Water Quality Storage versus Total Cost
(N=11)
10,000,000
1,000,000
100,000
10,000
1,000
Total Cost ($)
1,000
10,000
100,000
1,000,000
10,000,000
Water Quality Volume (cu. ft.)
y = 95.659x^0.6037
R^2 = 0.6112

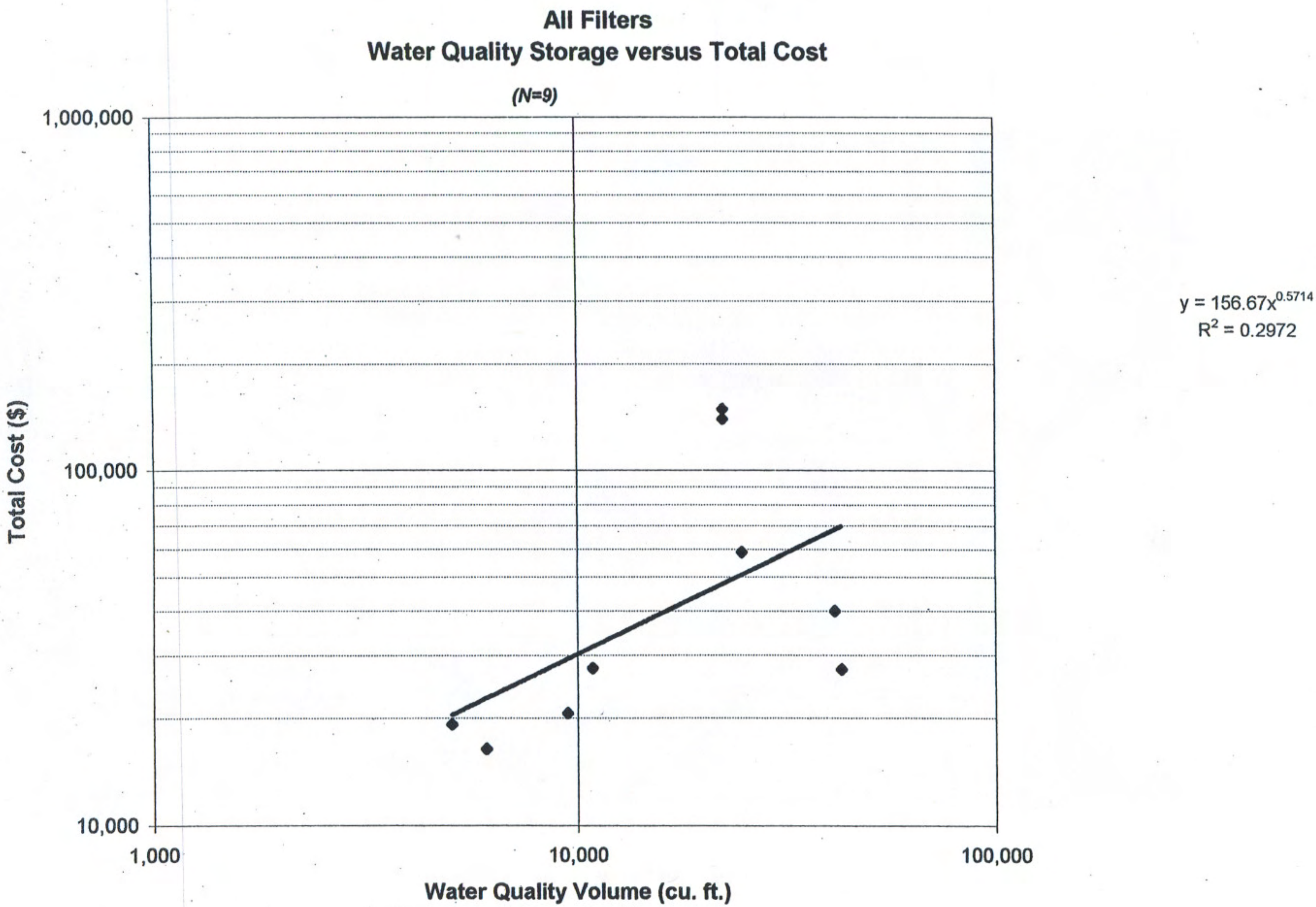

Wet ED Ponds
Water Quality Storage versus Construction Cost
(N=11)
10,000,000
1,000,000
100,000
10,000
1,000
Construction Cost ($)
1,000
10,000
100,000
1,000,000
10,000,000
Water Quality Volume (cu. ft.)
y = 74.64x^0.6114
R^2 = 0.5874


Wet Ponds
Total Storage versus Total Cost
(N=11)
10,000,000
1,000,000
100,000
10,000
1,000
Total Cost ($)
1,000
10,000
100,000
1,000,000
Total Volume (cu. ft.)
y = 106.59x^0.6147
R^2 = 0.5533

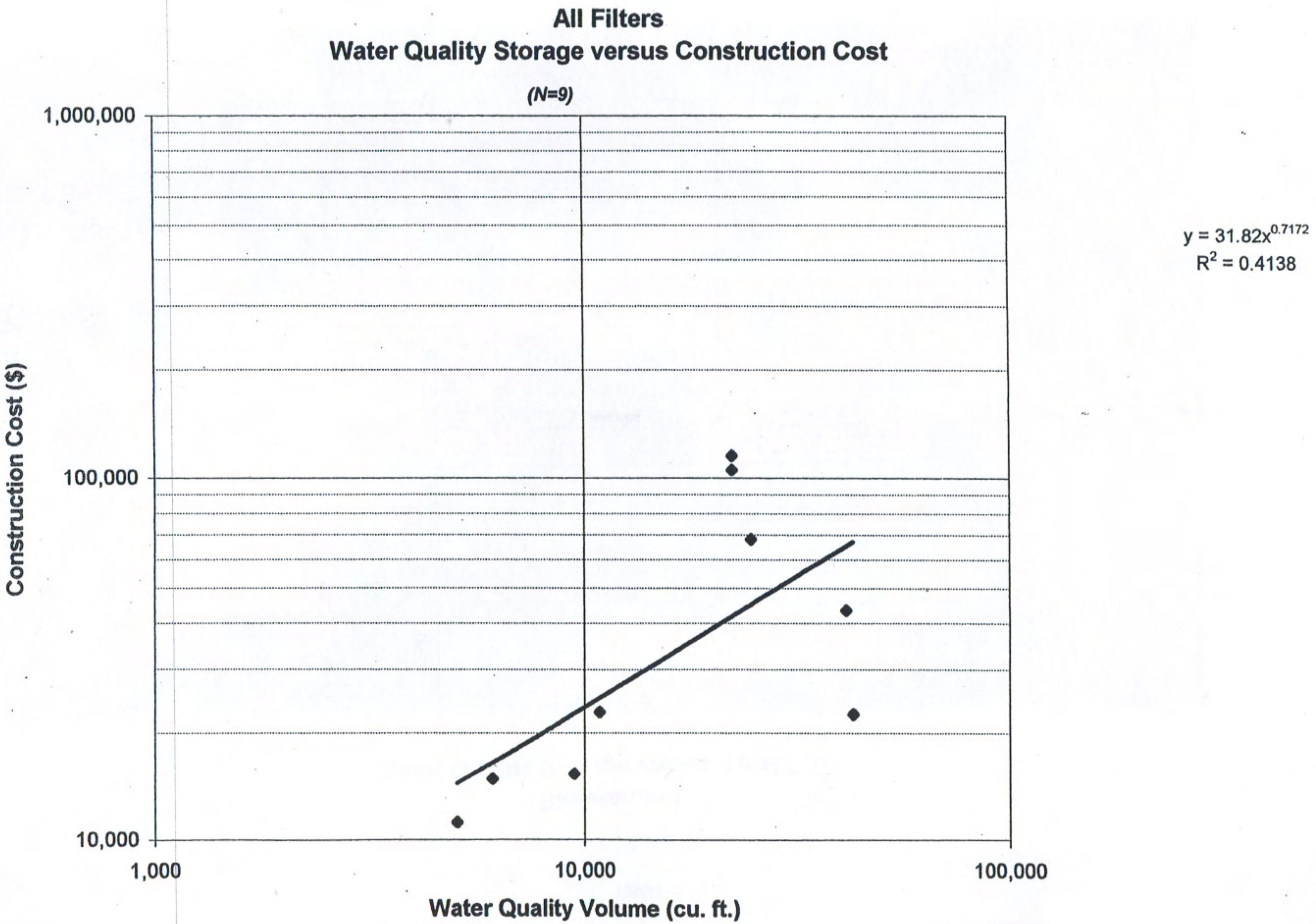

Wet Ponds
Total Volume versus Construction Cost
(N=11)
10,000,000
1,000,000
100,000
10,000
1,000
Construction Cost ($)
1,000
10,000
100,000
1,000,000
Total Volume (cu. ft.)
y = 196.43x^0.5531
R^2 = 0.4988

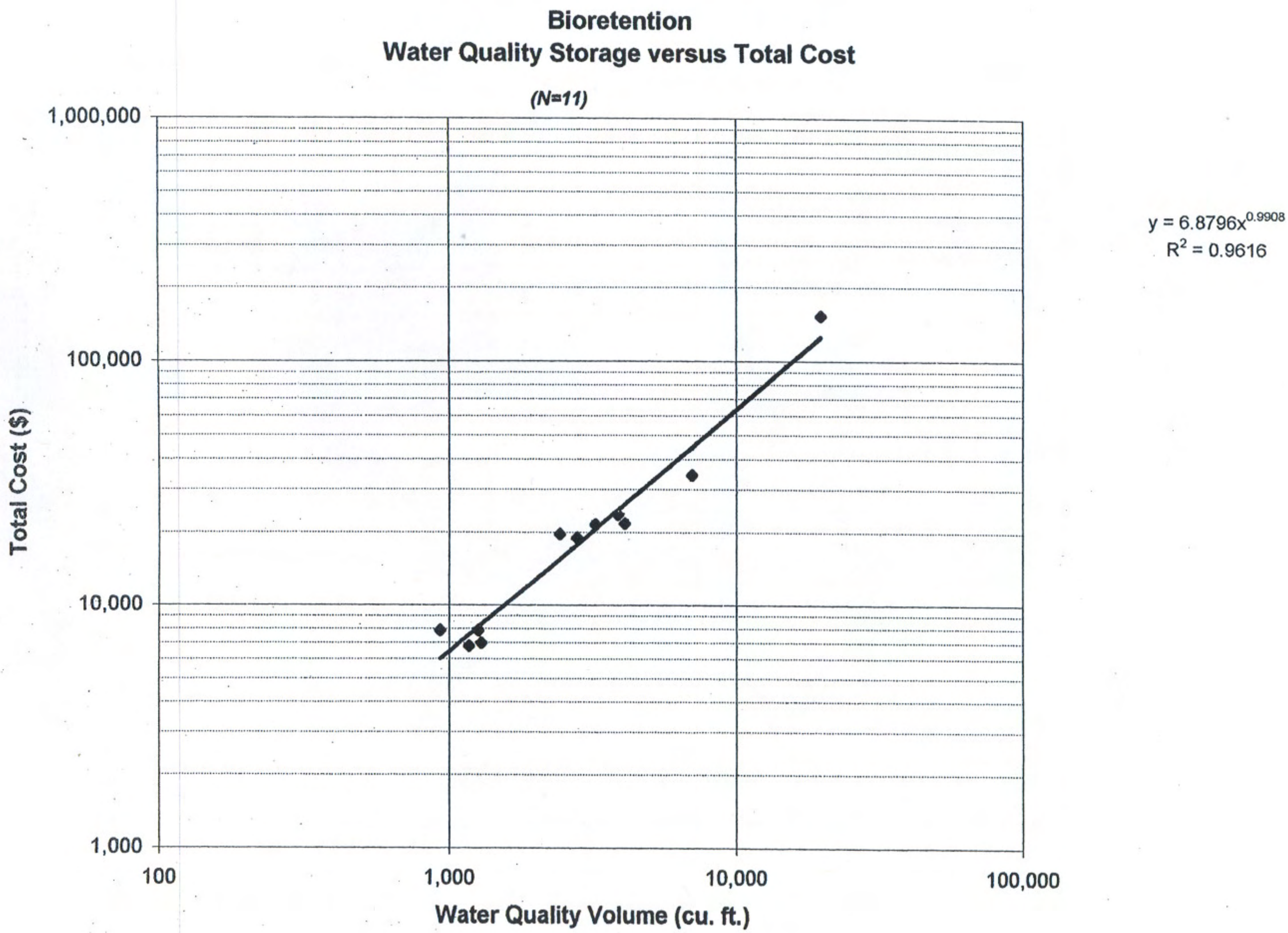

Wet Ponds
Water Quality Storage versus Total Cost
(N=11)
10,000,000
1,000,000
100,000
10,000
1,000
Total Cost ($)
1,000
10,000
100,000
1,000,000
Water Quality Volume (cu. ft.)
y = 3218.1x^0.3594
R^2 = 0.3273

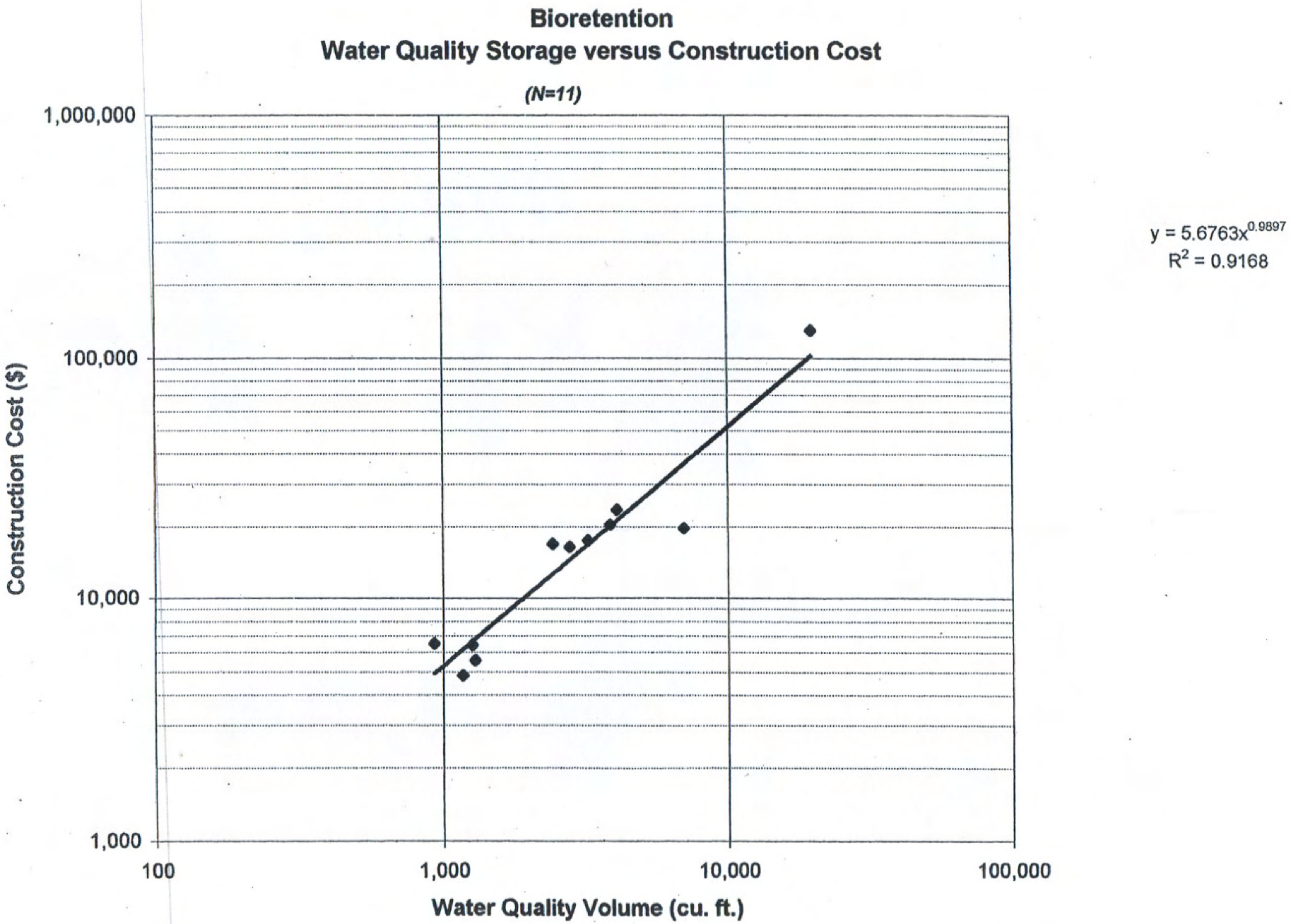

Wet Ponds
Water Quality Storage versus Construction Cost
(N=11)
10,000,000
1,000,000
100,000
10,000
1,000
Construction Cost ($)
1,000
10,000
100,000
1,000,000
Water Quality Volume (cu. ft.)
y = 4011.3x^0.3284
R^2 = 0.3041


All Filters
Water Quality Storage versus Total Cost
(N=9)
1,000,000
100,000
10,000
Total Cost ($)
1,000
10,000
100,000
Water Quality Volume (cu. ft.)
y = 156.67x^0.5714
R^2 = 0.2972

Con$-Storage, all




Bioretention
Water Quality Storage versus Total Cost
(N=11)
1,000,000
100,000
10,000
1,000
Total Cost ($)
100
1,000
10,000
100,000
Water Quality Volume (cu. ft.)
y = 6.8796x^0.9908
R^2 = 0.9616


Bioretention
Water Quality Storage versus Construction Cost
(N=11)
1,000,000
100,000
10,000
1,000
Construction Cost ($)
100
1,000
10,000
100,000
Water Quality Volume (cu. ft.)
y = 5.6763x^0.9897
R^2 = 0.9168