APPENDIX A

DETAILED INFORMATION ON TECHNOLOGIES AND THE DEVELOPMENT OF UNIT COSTS

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DETAILED INFORMATION ON TECHNOLOGIES AND THE DEVELOPMENT OF UNIT COSTS

This Appendix presents detailed information on the development of unit cost estimates for a set of technologies that may be used and actions that may be taken to meet requirements under the proposed §316(b) New Facility Rule. The Appendix provides additional description of many of the technologies and compliance actions to supplement the information presented in the main document.

Background

Facilities using cooling water may be subject to the proposed §316(b) New Facility Rule. A facility using cooling water can have either a once-through or a recirculating cooling system.

In a once-through system, the cooling water that is drawn in from a waterbody travels through the cooling system once to provide cooling and is then discharged, typically back to the waterbody from which it was withdrawn. The cooling water is withdrawn from a water source, typically a surface waterbody, through a cooling water intake structure (CWIS). Many facilities using cooling water (e.g., steam electric power generation facilities, chemical and allied products manufacturers, pulp and paper plants) need large volumes of cooling water, so the water is generally drawn in through one or more large CWIS, potentially at high velocities. Because of this, debris, tree limbs, and many fish and other aquatic organisms can be drawn toward or into the CWIS. Since a facility's cooling water system can be damaged or clogged by large debris, most facilities have protective devices such as trash racks, fixed screens, or traveling screens, on their CWIS. Some of these devices provide limited protection to fish and other aquatic organisms, but other measures such as the use of passive (e.g., wedgewire) screens, velocity caps, traveling screens with fish baskets, or the use of a recirculating cooling system may provide better protection and have greater capability to minimize adverse environmental impacts.[1]

In a recirculating system, the cooling water is used to cool equipment and steam, absorbing heat in the process, and is then cooled and recirculated to the beginning of the system to be used again for cooling. The heated cooling water is generally cooled in either a cooling tower or in a cooling lake/pond. In the process of being cooled, some of the water evaporates or escapes as steam. Flow lost through evaporation typically ranges from 0.5% to 1% of the total flow (Antaya, 1999). Also, because of the heating and cooling of recirculating water, mineral deposition occurs which necessitates some bleeding of water from the system. The water that is purged from the system to maintain chemical balance is called blow down. The amount of blow down is generally around 1% of the flow. Cooling towers may also have a small amount of drift, or windage loss, which occurs when some recirculating water is blown out of the tower by the wind or the velocity of the air flowing through the tower. The water lost to evaporation, blow down, and drift needs to be replaced by what is typically called makeup water. Overall, makeup water is generally 3% or less of the recirculating water flow.[2] Therefore, recirculating systems still need to draw in water and may have cooling water intakes. However, the volume of water drawn in is significantly less than in once-through systems so the likelihood of adverse environmental impacts as a result of the CWIS is much lower.[3] Also, some recirculating systems obtain their makeup water from ground water sources or public water supplies, and a small but growing number use treated wastewater from municipal wastewater treatment plants for makeup water.

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[1]CWIS devices used in an effort to protect fish also include other fish diversion and avoidance systems (e.g., barrier nets, strobe lights, electric curtains), which may be effective in certain conditions and for certain species.

[2]In some salt water cooling towers, however, makeup water can be as much as 15%.

[3]Manufacturer Brackett Green notes that closed loop systems (i.e., recirculating systems) normally require one-sixth the number of traveling screens as a power plant of equal size that has a once-through cooling system.

A. GENERAL COST INFORMATION

The cost estimates presented in this analysis include both capital costs and operations and maintenance (O&M) costs and are for primary technologies such as traveling screens and cooling towers and for actions such as extending intake piping to locate a CWIS outside the littoral zone. Facilities may install these technologies or take these actions to meet requirements of the proposed §316(b) New Facility Rule. Cooling tower cost estimates are presented for various types of cooling towers including towers fitted with features such as plume reduction and noise reduction. Estimated costs for traveling screens were developed mainly from cost information provided by vendors. The cost of installing other CWIS technologies such as passive screens and velocity caps are calculated by applying a cost factor based on the cost of traveling screens. All of the base cost estimates are for new sources.

To provide a relative measurement of the differences in cost across technologies, costs need to be developed on a uniform basis. The cost for many of the CWIS and flow reduction technologies depends on many factors, including site-specific conditions, and the relative importance of many of these factors varies from technology to technology. The factor that is most relevant and that seems to most affect cost is the total intake flow. Therefore, EPA selected total intake flow as the factor on which to base unit costs and thus use for basic cost comparisons. EPA developed cost estimates, in $/gallons per minute (gpm), for each of the technologies for use at a range of different total intake flow volumes.

EPA assumed average values or typical situations for the other factors that also impact the cost components. For example, EPA assumed an average debris level and an intake flow velocity of 0.5 feet per second (fps); EPA also used 1.0 fps for cost comparison purposes. EPA separately assessed the cost effect of variations from these average conditions as add-on costs. For instance, if the water being drawn in has a high debris level, this would tend to increase cost by about 20%.

EPA determined the specifications for each factor based on a review of information about the characteristics most likely to be encountered at a typical facility withdrawing cooling water. Cost factors used in this analysis and the assumed values/scenarios are listed below in Table A-1.

EPA's unit cost estimates for the selected technologies are based on the information provided by vendors. Most of the cost information came from well-established firms and from industry representatives who have lengthy experience in the design, vending, and installation of CWIS and cooling towers. Although only a limited number of vendors provided cost information, EPA believes the information is sufficient for developing unit cost estimates.

Industry representatives often preferred to remain anonymous whether they were helpful and provided cost information or not. Some industry representatives who provided cost information wanted to be acknowledged for providing information but without being directly linked to specific technology costs. For these reasons and because information from several sources was combined during analysis, some of the cost information presented in this document is not attributed to a specific industry source.

Table A-1. Basis for Development of Costs

<table>
<tr><th>Base Factor for Developing Unit Costs</th><th>Assumed Values of Other Factors for Base Costs</th></tr>
<tr><td>Costs were developed for flows of: [1]
< 10,000 gpm - 4 flows
10,000 to < 100,000 gpm - 20 flows
100,000 to 200,000 gpm - 4 flows
> 200,000 gpm - 1 flow.</td><td>Intake flow velocity = 0.5 fps, and 1.0 fps for comparison
Amount and type of debris = average/typical
Water quality = fresh water
Waterbody flow velocity = moderate flow
Accessability to intake = average/typical (no dredging needed, use of crane possible)</td></tr>
<tr><th colspan="2">Cost Elements</th></tr>
<tr><td colspan="2">Cost estimates of screens include non-metallic fish handling panels, a spray system, a fish trough, housings and transitions, continuous operating features (intermittent operation feature for traveling screens without fish baskets), a drive unit, frame seals, engineering, and installation. EPA separately estimated costs for spray wash pumps, permitting, and pilot studies. Cost estimates do not include a differential control system.

Cooling towers cost estimates are based on unit costs that include all costs associated with the design, construction, and commissioning of a standard fill cooling tower. Costs of cooling towers with various features, building materials, and types are calculated based on cost comparisons with standard cooling towers.

O&M costs were estimated for each type of technology. These costs were estimated, in part, using a percent of capital costs as a basis and considering additional factors.</td></tr>
<tr><th colspan="2">Potential Add-Ons to Cost</th></tr>
<tr><td colspan="2">Amount and type of debris = high or need for smaller than typical openings
Depth of waterbody = particularly shallow or deep
Water quality = salt or brackish water (extra cost for non-corrosive material for device and shorter life expectancy/higher replacement cost)
Waterbody flow velocity = stagnant or rapidly moving
Accessability to intake = cost of difficult installation (extra cost for dredging, extra cost for unusual installation due to site-specific conditions)
Existing intake structure = costs associated with retrofit and what existing structure(s) or conditions would cause the extra costs. For example, if an existing structure has an intake flow of 2.0 fps and the intake velocity will be reduced to 0.5 fps with a new device, additional equipment or changes to other equipment/structures of that part of the intake system may increase capital costs (albeit minimially) when compared to installing a new system.</td></tr>
<tr><td colspan="2">1) Cost estimates were developed for selected flows in each range (e.g., 4 different flows less than 10,000 gpm).
10,000 gpm = 14.4 MGD</td></tr>
</table>

The costs estimated for fish protection equipment are linked to both flow rates and intake width and depth. Cooling towers costs are costed based on the flow rate, in and out temperature delta (defined later), and the type of cooling tower. Some industry representatives provided information on how they conduct preliminary cost estimates for cooling towers. This is considered to be the "rule of thumb" in costing cooling towers [i.e., $/gallons per minute (gpm)]). Regional variations in costs do exist. For example, the costs of cooling towers in New England are generally more than for comparable cooling towers in the Mid Atlantic and Southeast parts of the country. In addition to the costs presented below, cost curves and equations are provided at the end of this Appendix. The cost curves and equations can be used to estimate costs for implementing technologies or taking actions for facilities across a range of intake flows. Additional supporting information can be found in *Cost Research and Analysis of Cooling Water Technologies for 316(b) Regulatory Options* (SAIC, 2000).

A.I. Flow

EPA determined preliminary intake flow values for the base factor based on data from the ICR (Information Collection Request) for the §316(b) industry questionnaire, a sampling of responses to the §316(b) industry screener questionnaire, a Utility Data Institute database (UDI, 1995), and industry brochures and technology background papers.[4] Data from these sources represent utility and nonutility steam electric facilities and industrial facilities that could be subject to prospective §316(b) requirements and are provided in Table A-2. EPA used these data to determine the range of typical intake flows for these types of facilities to ensure that the flows included in the cost estimates were representative. Through conversations with industry representatives, EPA determined the flows typically handled by available CWIS equipment and cooling towers. Facilities with greater flows would generally either use multiple screens, towers, or other technologies, or use a special design. Considering this information together, EPA selected flows for various screen sizes, water depths, and intake velocities for use in collecting cost data directly from industry representatives.

Table A-2. Flow Data

ICR (average intake flows by utility/industry category)			
Steam electric utilities:	178 MGD (124,000 gpm) for 1,093 facilities		
Steam electric non-utilities:	2.8 MGD (1,944 gpm) for 1,158 facilities		
Chemicals & allied products:	0.339 MGD (235 gpm) for 22,579 facilities		
Primary metals:	0.327 MGD (227 gpm) for 10,999 facilities		
Petroleum & coal products:	0.461 MGD (320 gpm) for 3,509 facilities		
Paper & allied products:	0.148 MGD (103 gpm) for 9,881 facilities		
UDI Database (design intake flow for steam electric utilities) (UDI, 1995)			
Up to 11,219 gpm (16.15 MGD)	401 units		
11,220-44,877 gpm (16.16-64.62 MGD)	465 units		
44,878-134,630 gpm (64.63-193.9 MGD)	684 units		
134,631-448,766 gpm (194-646.2 MGD)	453 units		
More than 448,766 gpm (646.2 MGD)	68 units		
Sampling of Responses from Industry Screener Questionnaire (daily intake flow for non-utilities)			
Up to 0.5 MGD (347 gpm)	6 facilities	>20-30.0 MGD (13,890-20,833 gpm)	2 facilities
>0.5-1.0 MGD (348-694 gpm)	1 facilities	>30-40.0 MGD (20,834-27,778 gpm)	2 facilities
>1-5.0 MGD (695-3,472 gpm)	3 facilities	>40-50.0 MGD (27,779-34,722 gpm)	1 facility
>5.0-10.0 MGD (3,473-6,944 gpm)	8 facilities	>50-100.0 MGD (34,723-69,444 gpm)	0 facilities
>10-20.0 MGD (6,945-13,889 gpm)	2 facilities	>100 MGD (>69,444 gpm)	1 facility
US Filter/Johnson Screens Brochure (ranges for flow definitions) (US Filter, 1998)			
Low flow:	200 to 4,000 gpm (0.288 to 5.76 MGD)		
Intermediate flow:	1,500 to 15,000 gpm (2.16 to 21.6 MGD)		
High flow:	5,000 to 30,000 gpm (7.2 to 43.2 MGD)		
Background Technology Papers (SAIC, 1994; SAIC, 1996)			
"Relatively low intake flow":	1-30 MGD (694-20,833 gpm)		
"Relatively small quantities of water":	up to 50,000 gpm (70 MGD)		

[4]EPA sent the *Industry Screener Questionnaire: Phase I Cooling Water Intake Structures* to about 2,500 steam electric non-utility power producers and manufacturers. This sample included most of the non-utility power producers that were identified by EPA and a subset of the identified manufacturers in industry groups that EPA determined use relatively large quantities of cooling water.

A.II. Additional Cost Considerations Included in the Analysis

The cost estimates include costs, such as design/engineering, process equipment, and installation, that are clearly part of getting a CWIS structure or cooling tower in place and operational. However, there are additional associated capital costs that may be less apparent but may also be incurred by a facility and have been included in the cost estimates either as stand alone cost items or included in installation and construction costs. These costs include:

- Mobilization and demobilization,
- Architectural fees,
- Contractor's overhead and profit,
- Process engineering,
- Sitework and yard piping,
- Standby power,
- Electrical allowance,
- Instrumentation and controls, and
- Contingencies.

Following is a brief description of these miscellaneous capital cost items to provide an indication of their general effect on capital costs. These descriptions are intended to help economists adjust costs to account for regional variations within the U.S.

A.II.a. Mobilization and Demobilization

Mobilization and demobilization costs are costs incurred by the contractor to assemble crews and equipment on-site and to dismantle semi-permanent and temporary construction facilities once the job is completed. The equipment that may be needed includes backhoes, bulldozers, front-end loaders, self-propelled scrapers, pavers, pavement rollers, sheeps-foot rollers, rubber tire rollers, cranes, temporary generators, trucks (including water and fuel trucks), and trailers. Mobilization costs also include bonds and insurance. To account for mobilization and demobilization costs, 2% to 5% is generally added to the total capital cost.

A.II.b. Architectural Fees

Estimates need to include the cost of the building design, architectural drawings, building construction supervision, construction engineering, and travel.

A.II.c. Contractor's Overhead and Profit

This element includes field supervision, main office expenses, tools and minor equipment, workers' compensation and employer's liability, field office expenses, performance and payment bonds, unemployment tax, profit, Social Security and Medicare, builder's risk insurance, and public liability insurance.

A.II.d. Process Engineering

Costs for this category include treatment process engineering, unit operation construction supervision, travel, system start-up engineering, study, design, operation and maintenance (O&M) manuals, and record drawings. These costs are generally estimated by adding 10% to 20% to the estimated construction cost.

A.II.e. Sitework and Yard Piping

Cost estimates for sitework should include site preparation, excavation, backfilling, roads, walls, landscaping, parking lots, fencing, storm water control, yard structures, and yard piping (interconnecting piping between treatment units). These costs are generally estimated by adding 5% to 15% to the estimated construction cost for sitework and 3% to 7% for yard piping.

For installation of CWIS technologies (e.g., screens), a yard piping cost of 5% of the total capital cost is sometimes used based on site-specific conditions. Therefore, to cost a specific site that might require extensive yard piping, a facility would multiply the total capital cost by a factor of 1.05. Cooling towers are more likely to require a significant amount of piping (for both new facilities and retrofits to existing facilities); these costs are already included in the "rule of thumb" cost estimate for cooling towers so an additional 5% was not applied.

A.II.f. Standby Power

Standby generators may be needed to produce power to the treatment and distribution system during power outages and should be included in cost estimates. These costs are generally estimated by adding 2% to 5% to the estimated construction cost.

A.II.g. Electrical Allowance (including yard wiring)

An electrical allowance should be made for electric wiring, motors, duct banks, MCCs, relays, lighting, etc. These costs are generally estimated by adding 10% to 15% to the estimated construction cost.

A.II.h. Instrumentation and Controls

Instrumentation and control (I&C) costs may include a facility control system, software, etc. The cost depends on the degree of automation desired for the entire facility. These costs are generally estimated by adding 3% to 8% to the estimated construction cost.

A.II.i. Contingencies

Contingency cost estimates include compensation for uncertainty within the scope of labor, materials, equipment, and construction specifications. This uncertainty factor can range from 5% to 25% of all capital costs, with an average of 10%.

Contingency costs can range from 2% to 20% for construction projects. CWIS technology projects are not typical construction projects since most of the construction is done at the manufacturing facility and site work mainly involves installation. So some of the uncertainties that could occur in typical construction projects are less likely in CWIS projects. Design and manufacture of the technology can be around 90% of the total cost for a project that involves a straightforward installation (e.g., no dredging). The approach used in this cost estimate is conservative and is considered to cover contingencies for typical CWIS technology or cooling tower projects.

In its 1992 study of cooling tower retrofit costs, Stone and Webster (1992) included, in its line item costs, an allowance for indeterminates (e.g., contingencies) of 15% for future utility projects. The Stone and Webster study involved major retrofit work on existing plants (i.e., converting a once through cooling system plant to recirculating), so the contingencies allowance fell in the higher end of the typical range.

A.III. Replacement Costs

EPA assumed that the technologies should be in place and reasonably expected to be operational for at least a 20-year period (the typical financing period). Therefore, O&M costs should meet that criteria. Vendors estimated the life expectancy of their devices under the base cost scenario and identified the conditions that most alter life expectancy and to what degree. EPA cost estimates generally cover the financial life of a project and do not include the cost of replacing the equipment when it reaches the end of its useful life. For most of the technologies examined here, the useful life of major equipment is often beyond the financing period of 20 years. For these reasons, EPA has not included replacement costs in the cost estimates for most of the technologies. However, for cooling towers, industry sources indicated that replacement of some major equipment during the financing period is necessary for the upkeep of the cooling tower. These costs tend to increase over the useful life of the tower and constitute a major O&M expenditure that needs to be accounted for. Therefore, EPA factored these periodic equipment replacement costs into the O&M cost estimates presented herein.

A.IV. Site-Specific Costs that are Not Included

The cost estimates developed for various technologies are intended to represent a National "typical average" cost estimate. The cost estimates should not be used as a project pricing tool as they cannot account for all the site-specific conditions for a particular project. Some highly site-specific capital costs are discussed generally in Section B.V of this Appendix but are not included in the cost estimates. Site-specific costs that are not accounted for in the cost estimates include the following:

- Regulatory requirements (e.g., permitting costs) that vary from one region/area to another,
- Testing (e.g., costs for pilot studies),
- Geotechnical allowance,
- Land aquisition costs, and
- Costs associated with facility/plant personnel.

Refer to Section B.V of this Appendix for additional discussion.

B. SPECIFIC COST INFORMATION FOR TECHNOLOGIES AND ACTIONS

The following presents information on potential compliance actions that a facility might take, including the installation of certain technologies, in order to meet requirements under the §316(b) New Facility Rule. The information presented includes the cost curves and unit costs developed for each potential compliance action. Estimated costs are presented in 1999 dollars. The cost equations and cost curves can be used to estimate costs. The equations and cost curves generally use flow as the basis for determining estimated costs (i.e., unit costs are in $/gpm). For screens, since flow is dependent on the flow velocity through the screen, different equations and cost curves are included for the two velocities of 0.5 fps and 1.0 fps.

B.I. Changing the Location of the CWIS in a Water Body

B.I.a. Extending the intake pipe

As part of complying with §316(b) New Facility Rule requirements, a facility may extend its intake pipe further into a waterbody in order to move the intake outside or further from the littoral zone.

Assumptions:

1) Criteria involving measurement of the Secchi Depth, change in the percent slope of the waterbody bottom, and substrate composition are being considered to determine whether a particular location is within the littoral zone. This information was not available for the proposed new facilities and is very site-specific. For costing purposes, EPA assumed that the littoral zone would end approximately 25 meters from the shoreline, so if a pipe extends at least 75 meters from the shoreline it would be 50 meters outside the littoral zone.[5] In a given location, the littoral zone may extend more or less than 25 meters from the shoreline into the water body, but for National costing purposes this distance is assumed to be a realistic estimate of a typical situation.

2) To meet the 50-meter littoral zone requirement, an intake pipe will sometimes need to be extended less than 75 meters from its original water intake design point since some intakes are planned for offshore. The maximum would be converting a shoreline intake to an offshore intake, which would require a 75-meter extension.[5] A 75-meter extension is the equivalent of about 246 foot extension.[6]

[5]EPA used a very conservative estimate of a pipe extension of 125 meters as a basis for estimating costs. Potentially the pipe extension length may be less and thus costs for a given facility taking this action could be lower, by as much as 30-40% depending on the pipe extension method used. This potential decrease in costs would have minimal impact on the overall estimated cost of the proposed Rule.

[6]1 meter = 3.281 feet

EPA analyzed intake data from several databases to assess whether assuming a shoreline intake and therefore an intake pipe extension of 75 meters (to be outside the littoral zone) for estimating compliance costs is justified. The 1995 Utility Data Institute database (UDI, 1995) contains data compiled for 991 steam electric utility plants in the United States, on a unit by unit basis. In total, there are data records for 2,759 units (i.e., intakes) at these plants. For all units, the UDI database shows that 50% have shoreline intakes and 10% have offshore intakes, while 19% use a canal and 14% use a well. If only the newer units are considered (those brought online in the last 10 years before the 1995 UDI survey was completed), the percent of shoreline intakes decreases to 39% and the portion of offshore intakes increases to 16% (14% use canals and 17% use wells). This may indicate a trend toward greater use of offshore intakes, however shoreline intakes are still much more common.

EPA sent the *Industry Screener Questionnaire: Phase I Cooling Water Intake Structures* to about 2,500 steam electric non-utility power producers and manufacturers. This sample included most of the non-utility power producers that were identified by EPA and a subset of the identified manufacturers in industry groups that EPA determined use relatively large quantities of cooling water. In total, 2,070 survey recipients filled out (at least in part) and returned a survey. Of these responses, EPA determined that 479 facilities were in-scope (i.e., facilities that have a point source as defined under the Clean Water Act, use cooling water, receive their cooling water supply from a surface water source, are currently in commercial service, and have an operating cooling water intake structure). Information on the type of CWIS configuration (e.g., shoreline-submerged intake, submerged offshore intake, intake canal) was requested on a facility-wide basis, so a respondent simply marked off all the configurations that applied, whether they were applicable at an individual CWIS or more than one CWIS. For the 479 in-scope facilities, the most common intake configuration is a submerged shoreline intake (183 facilities, or 38%). A significant number of in-scope facilities (147, or 31%) have at least one CWIS that is a submerged offshore intake. A smaller tier of facilities have intake canals or channels (102, or 21%) and/or surface shoreline intakes (81, or 17%).[7]

EPA also evaluated a database generated from data reported by utilities on U.S. Department of Energy *Form EIA-767 Steam Electric Plant Operation and Design Report 1997*. The database contains records for 1,537 units. Of the units likely to have cooling water intakes (e.g., they do not receive their water supply from a well or municipal source), approximately 60% have shoreline intakes (i.e., the intake is located 0 feet from the shore), and about 85% of the units have an intake that has a maximum distance from the shoreline of less than 410 feet (125 meters). These units represent 73% of all the intakes in the database. For the offshore intakes less than 410 feet from shore, the median distance for an intake is about 50 feet (15 meters) from the shoreline.

Since a majority of the units have intakes at the shoreline, and those with offshore intakes often extend only about 50 feet (about 15 meters) or less into the source water, it is reasonable to use a 75-meter (246-foot) extension as the estimated necessary extension length. Further, the underwater pipe laying costs will generally not change much for various lengths of pipe extension up to 75 meters since equipment rental, equipment and crew mobilization and demobilization, and onsite operations are the greatest costs and would be incurred regardless of the length of pipe laid for a distance less than 75 meters. Finally, because the cost estimates are assumed to be within 30 percent of the typical National average cost which would more than adequately account for variations due to changes in pipe distances. Therefore, the maximum distance is considered in these cost estimates.[8]

3) The source water (e.g., river) is wide enough so that a pipe extending 75 meters from one shore/river bank will also be at least 75 meters from the opposite shore/river bank and therefore meet the requirement on that side of the source water as well.

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[7]These values will change slightly after they are scaled to account for the fact that the survey included only a portion of identified manufacturers.

[8]EPA used a very conservative estimate of a pipe extension of 125 meters as a basis for estimating costs. Potentially the pipe extension length may be less and thus costs for a given facility taking this action could be lower, by as much as 30-40% depending on the pipe extension method used. This potential decrease in costs would have minimal impact on the overall estimated cost of the proposed Rule.

4) Installation: Since these are new facilities, they will already be incurring some cost to construct/install an intake. Therefore, putting in a longer intake pipe than originally planned does not entail all new construction and installation costs. Some of the crew and equipment would already be onsite, roads would already need to be built, and some earthwork would be done for the facility as originally planned. For estimating costs due to the §316(b) New Facility Rule, we need to consider the additional costs for the longer intake pipe. For example, if a shoreline intake has to become an offshore intake, costs for dredging, an underwater dive crew, and barge rental may now be incurred.

Costs:
The installation of a pipeline underwater requires skilled labor and special equipment and material. Unlike screens installed at water intakes, pressure is an important factor in the design and installation of the pipeline. The difference is that screens are much lighter than pipes and are open to water flow on both sides allowing for equalization of pressure, while pipelines are subject to axial tension and bending tension at the bottom side of the pipe body and bending compression at the upper side of the pipe body during laying. Therefore, special barges designed and equipped with special tools to avoid pipe distortion are used in such operations. Very often these barges use robots for pipe laying, trenching, and covering. The internal diameter of underwater pipeline ranges from 3" to 48" (very few cases are reported in the literature where pipe diameters reach 72"; this is mainly for oil and gas underwater pipeline application). Steel pipes are often used in underwater applications. Pipes are coated on the inside by a cement lining and on the outside by epoxy with a concrete overcoat or fiberglass wrapping. Prestressed concrete cylinder pipe (PCCP) and reinforced concrete pipe are also used. Steel pipe sections are joined together by full-penetration welding or flanged connectors. PCCP pipe sections are connected underwater by means of a device that uses a pump that creates a vacuum at the joint causing the sections to snap and tightly connect.

Pipes can either be placed on the waterbody floor or in a trench that is dug through the water body floor. For pipelines laid on the floor, where outcrops and uneven floors exist installation must include placing protective blankets under the pipe. For both water body floor and subfloor placements, pipelines need to be buried to protect them from fishing trawl boards, anchors, and from fatigue due to waterbody current stresses. Burying pipelines can be accomplished by sand bags, back fill with soil and a rock layer on top of the soil, and in some cases natural processes of sedimentation can be used to help protect the pipe. For underwater pipe laying, and particularly for short-distance underwater pipe laying, there are several ways to extend an intake pipe to 125 meters off the shore line. These methods include the use of special pipe laying vessels, the application of the bottom-pull method, and the micro-tunnel drilling method (discussed further below).

Generally, for lake applications steel piping is used and may be installed using any of the three pipe laying methods. For riverine applications, both PCCP and steel piping are used. All three of the installation methods are used for steel piping, while conventional pipe laying and micro-tunneling techniques are typically used for PCCP (although the bottom-pull method can be used). In ocean applications, PCCP is typically used and is installed using conventional methods.

1) Use of Conventional Pipe Laying Vessels
Special pipe laying vessels are vessels that are specially designed and constructed for underwater works. They are equipped with features such as a pipe delivery, handling, and storage station, a welding station, and a pipeline tensioner. These vessels are capable of handling 12-meter to 20-meter pipe sections and carrying out underwater welding. In addition to the pipe laying vessel, a supply vessel and a tug boat may be needed. A tug boat is sometimes used to pull the pipe laying vessel away from the shoreline in confined, high traffic, or low wake areas. The onshore support needed includes a crane to transport the pipes to the pipe laying vessel. Loading the pipe laying vessel with pipes would take about 1 to 2 hours (based on about 10 minutes per pipe section, assuming a pipe section length of 12 meters). The new generation pipe laying vessel, with a skilled crew and automatic welding equipment, can lay one mile of pipes on a good day. Based on this estimate, it is realistic to assume that one day would be sufficient for installing the pipe for a situation where the intake pipe needs to be extended up to 125 meters offshore. Because equipment and crew rental and mobilization/demobilization account for most of the cost, the cost per day of installing pipe is almost the same whether or not any pipe is laid (i.e., the pipe cost can be assumed to be a minor cost driver) (Gerwick, 2000). In a closed water body (e.g., lake), the pipe laying vessel has to be assembled and disassembled onsite. For large pipes a 150-ton crane also needs to be transported to site. The cost of transporting equipment varies greatly from site to site. Factors that contribute to cost variability include accessability to site, labor rates (union or non-union), and environmental and seasonal conditions. Box A-1 provides further detail.

Box A-1. Hypothetical Scenario for Installation of Pipe

The pipe laying vessel costs are based on the following base scenario:

Installation of pipes underwater, zero to 1 foot underwater visibility, 60-70 degree water temperature, low current lake, river, or ocean. The installation is to take place from the shoreline out to 125 meters (410 feet) offshore and requires the use of a barge or vessel with 4-point anchor capability and crane.

Job description: position and connect pipes to inlet flange. Lift, lower, and position via crane anchored to barge or vessel. Connect pipe sections and fittings. It is estimated that 500 feet of pipe can be installed per day using conventional pipe laying techniques depending on favorable logistic and environmental conditions and that the 125 meters of pipe can easily be installed in one day.

Rental cost of the pipe laying vessel (for pipes with diameter less than 12") is estimated at $90,000 to $110,000 depending on location of the vessel at the time of its rental. Installations in the Great Lakes area are estimated to be 10% to 15% higher because according to industry sources there are only four such vessels operating in that area, the labor rates are union rates, and the demand is greater. The rental price includes barge/vessel personnel (captain, crew, etc), material needed, and equipment needed to lay the pipe underwater.

Other considerations: Uncontrollable factors like barge availability, weather, water temperature, water depth, underwater visibility, currents, and onshore support can affect the daily production of the installation team. These variables always have to be considered when a job is quoted on a daily rate.

2) Bottom-Pull Method for Underwater Pipe Laying
In this method the pipeline is assembled onshore over a launching pad with rollers. The welded or flange-connected pipeline is then pulled by a barge that is anchored offshore. The barge rental cost is estimated at $20,000 per day. This estimated cost includes equipment, labor (crew and divers), and material needed for barge operation and pipe pulling. Additional costs for the application of this method include the rental of a small crane for onshore operation at $2000/day for pipes up to 12" in diameter and a heavy duty crane at $4,000/day for pipes of a pipe diameter greater than 12". The labor cost for welders and pipe connectors is estimated at $500 per day. The cost of using this method varies greatly from one site to another because it is important to have a site that is suitable for laying a pipe flat and therefore some sites require much more site preparation earth work than other sites. For costing purposes, EPA estimated that a combination tractor-crawler equipped with a bulldozer of 410 HP will be rented for two days for site preparation at an estimated cost of $1350/day. Some sites may not require this equipment.

3) Micro-Tunneling Technique
For river applications, drilling is the method of choice for pipe laying. This technique is the least disturbing to a site. Using this technique a shaft is drilled near the shoreline into which a horizontal boring machine is placed. The horizontal boring machine drills a micro tunnel where the intake pipe is installed under the river bed, sea floor, or lake floor. According to industry sources, the cost of this method does not differ much between a small pipe (12" diameter) and a large pipe (84" diameter) because the main costs are in shaft construction and the mobilization and demobilization of the crew and equipment. The lump-sum cost ranges between $1000 and $2000 per linear foot, with a typical budgetary cost for a small project (300 to 400 feet) at $1500/ft for large pipes. To develop cost curves and unit costs based on flow for micro-tunneling, EPA assumed a 125 meter pipe extension. Costs for this length of pipe extension were calculated and then related to the flows that would be reasonable for pipes of various sizes. See the end of this Appendix for the cost curves and equations for pipe extension.

B.I.b. Dredging the intake canal

Relocating a proposed intake pipe so that it is outside the littoral zone can be accomplished by either extending the pipe (further) away from the shoreline or placing a shoreline intake deeper. For facilities using an intake canal or channel, the facility may need to dredge the canal or channel deeper so that the intake pipe is located outside the littoral zone. The size of the littoral zone is very site-specific. The extent of the littoral zone of a given water body depends on factors such as water depth, season, rain episodes (amounts, frequency, and intensity), the quantity and quality of runoff and other discharges, biota and biomass, sediment disturbance, and water quality in the area of interest. The littoral zone would be determined using a site-specific measurement of Secchi Depth.

Assumptions:
1) Moving a cooling water intake structure to outside the littoral zone may be done by relocating the pipe to a greater depth. This depth will depend on the quality of water in the lake. Based on the depth location required, the pipe would be extended a certain amount from the shoreline to reach the depth. Table A-3 shows the depths EPA estimates are needed to locate the pipe below the littoral zone for different categories of water quality. EPA then estimated the distance from the shoreline that a pipe would need to be extended to reach that water depth. These estimated depths are based on field experience, discussions with ecologists and biologists, and best professional judgement. Cost estimates for extending an intake pipe were presented in the previous section.

Table A-3. Estimated Pipe Placement to Reach Outside the Littoral Zone

Water Quality	Depth of Water to Reach Outside Littoral Zone (feet)	Distance from Shoreline to Reach the Depth (feet)
Pristine	15	150
Average	8	100
Turbid	4	10

2) Shoreline intakes often have a dredged channel with a baffle or skimmer wall and withdraw water from below the surface, possibly from the bottom. To retain this type of intake (instead of extending it offshore), the channel would have to be deep enough to pull in water from outside the littoral zone. To accomplish this, dredging of the canal at the mouth of the river and near the power plant pumping station would need to be done.

Costs:
1) Increasing the depth of the proposed intake to below the littoral zone is assumed to be achieved by further deepening the planned intake to a level below the littoral zone. For the smallest size deepening operation, it is assumed that 10,000 CY of sediments will be removed using a dredger for the small size canal (i.e., assuming that the dimensions are 10 by 10 by 100 yards). It is also assumed that increasing the depth below the littoral zone for the large size canal entails the dredging of an area of 10 by 40 by 100 yards. Widening, dredging, and dumping operations are assumed to be accomplished using a 2000 gallons per CY dredger at $12.25 per CY. These costs apply to situations where sediments are disposed of onsite. If sediments are contaminated, the permitting authority may require transport for offsite disposal which may double or triple the operational costs. See the end of this Appendix for costs curves.

B.II. Reducing Design Intake Flow

B.II.a. Switching to a recirculating system

As noted earlier, in a recirculating system cooling water is used to cool equipment and steam, and absorbs heat in the process. The cooling water is then cooled and recirculated to the beginning of the system to be used again for cooling. Recirculating the cooling water in a system vastly reduces the amount of cooling water needed. The method most frequently used to cool the water in a recirculating system is putting the cooling water through a cooling tower. Therefore, EPA chose to cost cooling towers as the technology used to switch a once through cooling system to a recirculating system.

Based on discussions with industry representatives, the factors that generally have the greatest impact on cost appear to be the flow desired by the facility, delta (the difference between cold water temperature and ambient wet bulb temperature), tower type, and environmental considerations. Physical site conditions (e.g., topographic conditions, soils and underground conditions, water quality) affect cost, but in most situations are secondary to the primary cost factors. Table A-4 presents relative capital and operation cost estimates for various cooling towers in comparison to the conventional, basic Douglas Fir cooling tower as a standard.

Table A-4. Relative Cost Factors for Various Cooling Tower Types[1]

Tower Type	Capital Cost Factor (%)	Operation Cost Factor (%)
Douglas Fir	100	100
Redwood	112[2]	100
Concrete	140	90
Steel	135	98
Fiberglass Reinforced Plastic	110	98
Splash Fill	120	150
Non-Fouling Film Fill	110	102
Mechanical draft	100	100
Natural draft (concrete)	175	35
Hybrid [Plume abatement (32DBT)]	250-300	125-150
Dry/wet	375	175
Air condenser (steel)	250-325	175-225
Noise reduction (10dBA)	130	107

1) Percent estimates are relative to the Douglas Fir cooling tower.
2) Redwood cooling tower costs may be higher because redwood trees are a protected species, particularly in the Northwest.

Sources: Mirsky et al. (1992), Mirsky and Bauthier (1997), and Mirsky (2000).

There are two general types of cooling towers, wet and dry. Wet cooling towers, which are the far more common type, reduce the temperature of the water by bringing it directly into contact with large amounts of air. Through this process, heat is transferred from the water to the air which is then discharged into the atmosphere. Part of the water evaporates through this process thereby having a cooling effect on the rest of the water. This water then exits the cooling tower at a temperature approaching the wet bulb temperature of the air. For dry cooling towers, the water does not come in direct contact with the air, but instead travels in closed pipes through the tower. Air going through the tower flows along the outside of the pipe walls and absorbs heat from the pipe walls which absorb heat from the water in the pipes. Dry cooling towers tend to be much larger and more costly than wet towers since the dry cooling process is less efficient. Also, the effluent water temperature is warmer since it only approaches the dry bulb temperature of the air (not the cooler wet bulb temperature). Hybrid wet-dry towers, which combine dry heat exchange surfaces with standard wet cooling towers, are plume abatement towers. These towers tend to be used most where plume abatement is required by local authorities. Technologies for achieving low noise and low drift can be fitted to all types of towers.

Other characteristics of cooling towers include:

- ***Air flow*****:** Mechanical draft towers use fans to induce air flow, while natural draft (i.e., hyperbolic) towers induce natural air flow by the chimney effect produced by the height and shape of the tower. For towers of similar capacity, natural draft towers typically require significantly less land area and have lower power costs (i.e., fans to induce air flow are not needed) but have higher initial costs (particularly because they need to be taller) than mechanical draft towers. Both mechanical draft and natural draft towers can be designed for air to flow through the fill material using either a crossflow (air flows horizontally) or counterflow (air flows vertically upward) design, while the water flows vertically downward. Counterflow towers tend to be more efficient at achieving heat reduction but are generally more expensive to build and operate because clearance needed at the bottom of the tower means the tower needs to be taller.

- ***Mode of operation*****:** Cooling towers can be either recirculating (water is returned to the condenser for reuse) or nonrecirculating (tower effluent is discharged to a receiving waterbody and not reused). Facilities using nonrecirculating types (i.e., "helper" towers) draw large flows for cooling and therefore do not provide fish protection for §316(b) purposes, so the information in this report is not intended to address non-recirculating towers.

- ***Construction materials*****:** Towers can be made from concrete, steel, wood, and/or fiberglass.

Generally, all cooling towers with plume abatement features are hybrid towers. According to an industry source, attempts to modify towers with special designs and construction features to abate plumes was prohibitively expensive. Natural draft towers are concrete towers, although some old natural draft wood cooling towers do exist. Therefore, for costing purposes, concrete is assumed to be the material used for building natural draft cooling towers.

To collect data and cost estimates on cooling towers, EPA obtained a list of cooling tower manufacturers, suppliers and users from the Cooling Tower Institute (CTI). CTI members are local and international. Representatives of the cooling tower industry were contacted as part of an effort to get information on firms involved in the design, manufacture, and supply of cooling water intake structures and fish protection equipment. The CTI members contacted indicated that in general they rely on groundwater or treated municipal water sources for supplemental/makeup water for cooling. Other CTI members, though listed as manufacturers, indicated that they specialize in repairing cooling towers only and are not involved in repairing intake facilities. Many CTI members indicated that they specialize in recirculating systems that require little or no water (after initial startup). For example, GEA Integrated Cooling Technologies provided brochures of its latest line of cooling equipment that does not need cooling water. Based on discussions with GEA representatives and as reflected in its brochures, GEA specializes in dry cooling systems and in hybrid systems that use very little water from municipal or ground sources. The air cooled condensers provide cooling towers with plume abatement and water savings. GEA also provided information on a system that uses a hybrid cooling system because the facility had a discharge permit for half the flow generated at the facility.

Cooling tower industry representatives provided names and telephone numbers of persons and firms that are involved in the design and installation of cooling towers, CWIS technologies, and associated equipment, or represent firms that do. The representatives provided contacts at two prominent engineering firms, Bechtel and Black &Veatch, who were contacted to request information.

A Bechtel senior engineer indicated that the cost data that Bechtel has are confidential. However, he provided his personal experience on factors that drive the costs of cooling towers and their associated intake structures and screening equipment. Typically, and particularly based on the experience gained in power plants, the size of an intake structure is determined from the financial feasibility study of the project. The financial feasibility study determines the need for power, the expected power loads, and the ability of the community to pay. Based on that study, and on an environmental and socioeconomic study that follows the financial study, the project site (including the water intake site) is selected. The cost of the turnkey project is estimated based on the concepts outlined in the site selection study.[9] Typically, the cost of the project is determined based on the following factors: type of equipment to be cooled (e.g., coal fired equipment, natural gas powered equipment); location of the water intake (on a river, lake, or seashore); amount of power to-be-generated (e.g., 50 mega Watt vs. 200 mega Watt); and volume of water needed. The volume of water needed for cooling depends on the following critical parameters: water temperature, make of equipment to be used (e.g, G.E turbine vs. ABB turbine, turbine with heat recovery system and turbine without heat recovery system), discharge permit limits, water quality (particularly for wet cooling towers), and type of wet cooling tower (i.e., whether it is a natural draft or a mechanical draft).

To estimate costs specifically for installing and operating a particular cooling tower, important factors include:

[9]For a turnkey project, the engineering firm typically manages design, construction, and initial operation of the system, and then "turns the key" over to the facility for the facility to continue operating and maintaining the system.

- ***Condenser heat load and wet bulb temperature (or approach to wet bulb temperature)*:** Largely determine the size needed. Size is also affected by climate conditions.

- ***Plant fuel type and age/efficiency*:** Condenser discharge heat load per Mega watt varies greatly by plant type (nuclear thermal efficiency is about 33% to 35%, while newer oil-fired plants can have nearly 40% thermal efficiency, and newer coal-fired plants can have nearly 38% thermal efficiency).[10] Older plants typically have lower thermal efficiency than new plants.

- ***Topography*:** May affect tower height and/or shape, and may increase construction costs due to subsurface conditions. For example, sites requiring significant blasting, use of piles, or a remote tower location will typically have greater installation/construction cost.

- ***Material used for tower construction*:** Wood towers tend to be the least expensive, followed by fiberglass reinforced plastic, steel, and concrete. However, some industry sources claim that Redwood capital costs might be much higher compared to other wood cooling towers, particularly in the Northwest U.S., because Redwood trees are a protected species. Factors that affect the material used include chemical and mineral composition of the cooling water, cost, aesthetics, and local/regional availability of materials.

- ***Pollution control requirements*:** Air pollution control facilities require electricity to operate. Local requirements to control drift, plume, fog, and noise and to consider aesthetics can also increase costs for a given site (e.g., different design specifications may be required).

Summaries of some EPRI research on dry cooling systems and wet-dry supplemental cooling systems note that dry cooling towers may cost as much as four times more than conventional wet towers (EPRI, 1986a and 1986b).

Capital Cost of Cooling Towers

Two cooling tower industry managers with extensive experience in selling and installing cooling towers to power plants and other industries provided information on how they estimate budget capital costs associated with a wet cooling tower. The rule of thumb they use is $30/gpm for a delta of 10 degrees and $50/gpm for a delta of 5 degrees.[11] This cost is for a "small" tower (flow less than 10,000 gpm) and equipment associated with the "basic" tower, and does not include installation. Above 10,000 gpm, to account for economy of scale, the unit cost was lowered by $5/gpm over the flow range up to 204,000 gpm. For flows greater than 204,000 gpm, a facility may need to use multiple towers or a custom design. Combining this with the variability in cost among various cooling tower types, costs for various tower types and features were calculated for the flows used in calculating screen capacities at 1 ft/sec and 0.5 ft/sec. Based on discussions with industry representatives, EPA estimated installation costs as 80% of cooling tower equipment cost. These estimates are presented in Table A-5. See the end of this Appendix for cost curves and equations.

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[10]With a 33% efficiency, one-third of the heat is converted to electric energy and two-thirds goes to waste heat in the cooling water.

[11]The delta is the difference between the cold water (tower effluent) temperature and the tower wet bulb temperature. This is also referred to as the design approach. For example, at design conditions with a delta or design approach of 5 degrees, the tower effluent and blowdown would be 5 degrees warmer than the wet bulb temperature. A smaller delta (or lower tower effluent temperature) requires a larger cooling tower and thus is more expensive.

Table A-5. Estimated Capital Costs of Cooling Towers without Special Environmental Impact Mitigation Features (1999 Dollars)

Flow (gpm)	Basic Douglas Fir Cooling Tower Cost[1]	Redwood Tower	Concrete Tower	Steel Tower	Fiberglass Reinforced Plastic Tower
2000	$108,000	$121,000	$151,000	$146,000	$119,000
4000	$216,000	$242,000	$302,000	$ 292,000	$238,000
7000	$378,000	$423,000	$529,000	$ 510,000	$416,000
9000	$486,000	$544,000	$680,000	$ 656,000	$535,000
11,000	$594,000	$665,000	$832,000	$ 802,000	$653,000
13,000	$702,000	$786,000	$983,000	$ 948,000	$772,000
15,000	$810,000	$907,000	$1,134,000	$1,094,000	$891,000
17,000	$918,000	$1,028,000	$1,285,000	$1,239,000	$1,010,000
18,000	$972,000	$1,089,000	$1,361,000	$1,312,000	$1,069,000
22,000	$1,148,400	$1,286,000	$1,608,000	$1,550,000	$1,263,000
25,000	$1,305,000	$1,462,000	$1,827,000	$1,762,000	$1,436,000
28,000	$1,461,600	$1,637,000	$2,046,000	$1,973,000	$1,608,000
29,000	$1,513,800	$1,695,000	$2,119,000	$2,044,000	$1,665,000
31,000	$1,618,200	$1,812,000	$2,265,000	$2,185,000	$1,780,000
34,000	$1,774,800	$1,988,000	$2,485,000	$2,396,000	$1,952,000
36,000	$1,879,200	$2,105,000	$2,631,000	$2,537,000	$2,067,000
45,000	$2,268,000	$2,540,000	$3,175,000	$3,062,000	$2,495,000
47,000	$2,368,800	$2,653,000	$3,316,000	$3,198,000	$2,606,000
56,000	$2,822,400	$3,161,000	$3,951,000	$3,810,000	$3,105,000
63,000	$3,175,200	$3,556,000	$4,445,000	$4,287,000	$3,493,000
67,000	$3,376,800	$3,782,000	$4,728,000	$4,559,000	$3,714,000
73,000	$3,679,200	$4,121,000	$5,151,000	$4,967,000	$4,047,000
79,000	$3,839,400	$4,300,000	$5,375,000	$5,183,000	$4,223,000
94,000	$4,568,400	$5,117,000	$6,396,000	$6,167,000	$5,025,000
102,000	$4,957,200	$5,552,000	$6,940,000	$6,692,000	$5,453,000
112,000	$5,443,200	$6,096,000	$7,620,000	$7,348,000	$5,988,000
146,000	$7,095,600	$7,947,000	$9,934,000	$9,579,000	$7,805,000
157,000	$7,347,600	$8,229,000	$10,287,000	$9,919,000	$8,082,000
204,000	$9,180,000	$10,282,000	$12,852,000	$12,393,000	$10,098,000

1) Includes installation at 80% of equipment cost for a delta of 10 degrees.

Using the estimated costs, EPA developed a cost equation using a polynomial curve fitting function. Table A-6 presents cost equations for basic tower types built with different building materials and assuming a delta of 10 degrees. The cost equations presented in Table A-6 include installation costs. The “x” in the presented cost equations is for flow in gpm and the “y” is in dollars.

Table A-6. Capital Cost Equations of Cooling Towers without Special Environmental Impact Mitigation Features (Delta 10 degrees)

Tower Type	Capital Cost Equation[1]	Correlation Coefficient
Douglas Fir	$y = -9E\text{-}11x^3 - 8E\text{-}06x^2 + 50.395x + 44058$	$R^2 = 0.9997$
Redwood	$y = -1E\text{-}10x^3 - 9E\text{-}06x^2 + 56.453x + 49125$	$R^2 = 0.9997$
Steel	$y = -1E\text{-}10x^3 - 1E\text{-}05x^2 + 68.039x + 59511$	$R^2 = 0.9997$
Concrete	$y = -1E\text{-}10x^3 - 1E\text{-}05x^2 + 70.552x + 61609$	$R^2 = 0.9997$
Fiberglass Reinforced Plastic	$y = -1E\text{-}10x^3 - 9E\text{-}06x^2 + 55.432x + 48575$	$R^2 = 0.9997$
1) x is for flow in gpm and y is cost in dollars.		

Using the cost comparison information published by Mirsky et al. (1992), EPA calculated the costs of cooling towers with various additional features. These costs are presented in Table A-7. Table A-7 presents capital costs of the Douglas Fir Tower with various features. The cost for other types of cooling towers are also calculated.

Table A-8 presents cost equations for cooling towers with special environmental mitigation features, built with different building materials and assuming a delta of 10 degrees. The cost equations presented in Table A-8 include installation costs. The "x" in the presented cost equations is for flow in gpm and the "y" is in dollars.

At the end of this Appendix, cost curves with equations are also presented for other types of cooling towers.

Operation and Maintenance (O&M) Cost of Cooling Towers

Estimating annual O&M costs for cooling towers is an involved process since the estimator has to account for many interrelated dependent and independent cost drivers. These cost drivers include:

- Size of the cooling tower,
- Material from which the cooling tower is built,
- Various features that the cooling tower may include,
- Source of make-up water,
- How blow down water is disposed, and
- Increase in maintenance costs as the tower useful life diminishes.

For example, if make-up water is obtained from a lesser quality source, additional treatment may be required to prevent biofouling in the tower.

Table A-7. Capital Costs of Douglas Fir Cooling Towers with Special Environmental Impact Mitigation Features (Delta 10 degrees) (1999 Dollars)

Flows (gpm)	Douglas Fir Cooling Tower	Splash Fill	Non-fouling Film Fill	Noise Reduction 10 dBA	Dry/wet	Hybrid Tower (32DBT Plume Abatement)
2000	$108,000	$130,000	$119,000	$140,000	$405,000	$324,000
4000	$216,000	$259,000	$238,000	$281,000	$810,000	$648,000
7000	$378,000	$454,000	$416,000	$491,000	$1,418,000	$1,134,000
9000	$486,000	$583,000	$535,000	$632,000	$1,823,000	$1,458,000
11,000	$594,000	$713,000	$653,000	$772,000	$2,228,000	$1,782,000
13,000	$702,000	$842,000	$772,000	$913,000	$2,633,000	$2,106,000
15,000	$810,000	$972,000	$891,000	$1,053,000	$3,038,000	$2,430,000
17,000	$918,000	$1,102,000	$1,010,000	$1,193,000	$3,443,000	$2,754,000
18,000	$972,000	$1,166,000	$1,069,000	$1,264,000	$3,645,000	$2,916,000
22,000	$1,148,400	$1,378,000	$1,263,000	$1,493,000	$4,307,000	$3,445,000
25,000	$1,305,000	$1,566,000	$1,436,000	$1,697,000	$4,894,000	$3,915,000
28,000	$1,461,600	$1,754,000	$1,608,000	$1,900,000	$5,481,000	$4,385,000
29,000	$1,513,800	$1,817,000	$1,665,000	$1,968,000	$5,677,000	$4,541,000
31,000	$1,618,200	$1,942,000	$1,780,000	$2,104,000	$6,068,000	$4,855,000
34,000	$1,774,800	$2,130,000	$1,952,000	$2,307,000	$6,656,000	$5,324,000
36,000	$1,879,200	$2,255,000	$2,067,000	$2,443,000	$7,047,000	$5,638,000
45,000	$2,268,000	$2,722,000	$2,495,000	$2,948,000	$8,505,000	$6,804,000
47,000	$2,368,800	$2,843,000	$2,606,000	$3,079,000	$8,883,000	$7,106,000
56,000	$2,822,400	$3,387,000	$3,105,000	$3,669,000	$10,584,000	$8,467,000
63,000	$3,175,200	$3,810,000	$3,493,000	$4,128,000	$11,907,000	$9,526,000
67,000	$3,376,800	$4,052,000	$3,714,000	$4,390,000	$12,663,000	$10,130,000
73,000	$3,679,200	$4,415,000	$4,047,000	$4,783,000	$13,797,000	$11,038,000
79,000	$3,839,400	$4,607,000	$4,223,000	$4,991,000	$14,398,000	$11,518,000
94,000	$4,568,400	$5,482,000	$5,025,000	$5,939,000	$17,132,000	$13,705,000
102,000	$4,957,200	$5,949,000	$5,453,000	$6,444,000	$18,590,000	$14,872,000
112,000	$5,443,200	$6,532,000	$5,988,000	$7,076,000	$20,412,000	$16,330,000
146,000	$7,095,600	$8,515,000	$7,805,000	$9,224,000	$26,609,000	$21,287,000
157,000	$7,347,600	$8,817,000	$8,082,000	$9,552,000	$27,554,000	$22,043,000
204,000	$9,180,000	$11,016,000	$10,098,000	$11,934,000	$34,425,000	$27,540,000

Table A-8. Capital Cost Equations of Douglas Fir Cooling Towers with Special Environmental Impact Mitigation Features (Delta 10 degrees)

Tower Type	Capital Cost Equation[1]	Correlation Coefficient
Douglas Fir	$y = -9E\text{-}11x^3 - 8E\text{-}06x^2 + 50.395x + 44058$	$R^2 = 0.9997$
Splash Fill	$y = -4E\text{-}05x^2 + 62.744x + 22836$	$R^2 = 0.9996$
Non-fouling Film Fill	$y = -1E\text{-}10x^3 - 9E\text{-}06x^2 + 55.432x + 48575$	$R^2 = 0.9997$
Noise Reduction 10 dBA	$y = -1E\text{-}10x^3 - 1E\text{-}05x^2 + 65.517x + 57246$	$R^2 = 0.9997$
Dry/Wet	$y = -0.0001x^2 + 196.07x + 71424$	$R^2 = 0.9996$
Hybrid Tower (Plume Abatement 32DBT)	$y = -3E\text{-}10x^3 - 2E\text{-}05x^2 + 151.18x + 132225$	$R^2 = 0.9997$
1) x is flow in gpm and y is cost in dollars.		

The estimated annual O&M costs presented below are for cooling towers designed at a delta of 10 degrees. Annual O&M costs for cooling towers designed at a delta of 5 degrees can be calculated using the procedure detailed below. To calculate annual O&M costs for various types of cooling towers, EPA made the following assumptions:

- For small cooling towers, 5% of capital costs is attributed to chemical costs and routine maintenance. To account for economy of scale, that percentage is gradually decreased to 2% for the largest size cooling tower. This assumption is based on discussions with industry representatives and information provided by them.

- Based on discussions with industry representatives, 2% of the tower flow is lost to evaporation and/or blow down.

- To account for the costs of makeup water and disposal of blow down water, EPA used three scenarios. The first scenario is based on the facility using surface water sources for makeup water and disposing of blow down water either to a pond or back to the surface water source at a combined cost of $0.5/1000 gallons. The second scenario is based on the facility using gray water (treated municipal wastewater) for makeup water and disposing of the blow down water into a POTW sewer line at a combined cost of $3/1000 gallons. The third scenario is based on the facility using municipal sources for clean makeup water and disposing of the blow down water into a POTW sewer line at a combined cost of $4/1000 gallons.

- Based on discussions with industry representatives, maintenance costs are 10% of capital costs for towers over 5 years old, 20% for towers over 10 years old, and 30% for towers more than 15 years old. Averaging these percentages over a period of 20 years yields a maintenance cost at 15% of capital cost [((5*0/100)+(5*10/100)+(5*20/100)+(5*30/100))/20)].

To account for the variation in maintenance costs among cooling tower types, a scaling factor is used. Douglas Fir is the type with the greatest maintenance cost, followed by Redwood, steel, concrete, and fiberglass. For additional cooling tower features, a scaling factor was used to account for the variations in maintenance (e.g., splash fill and non-fouling film fill are the features with the lowest maintenance costs).

Using the operation cost comparison information published by Mirsky et al. (1992) and maintenance cost assumptions set out above, EPA calculated estimated costs of O&M for various types of cooling towers with and without additional features. EPA then developed cost equations from the generated cost data points. The equations and costs are shown in Tables A-9 through A-14 for the first and second scenarios for different types of towers (i.e., various materials and features). Cost curves and equations for O&M costs for additional types of cooling towers are presented at the end of the Appendix.

Note that these cost estimates and equations are for total O&M costs. Stone and Webster (1992) presents a value for additional annual O&M costs equal to approximately 0.7% of the capital costs for a retrofit project. Stone and Webster's estimate is for the amount O&M costs are expected to *increase* when plants with once through cooling systems are retrofit with cooling towers to become recirculating systems, and therefore do not represent total O&M costs.

Table A-9. Total Annual O&M Cost Equations by Tower Type - 1st Scenario

Cooling Tower Material Type	Total Annual O&M Cost Equations[1]	Correlation Coefficient
Concrete	$y = -8E\text{-}06x^2 + 13.291x + 13850$	$R^2 = 0.9999$
Douglas Fir	$y = -8E\text{-}06x^2 + 14.524x + 11183$	$R^2 = 0.9999$
Redwood	$y = -8E\text{-}06x^2 + 13.938x + 11895$	$R^2 = 0.9999$
Steel	$y = -8E\text{-}06x^2 + 14.183x + 13605$	$R^2 = 0.9999$
Fiberglass Reinforced Plastic	$y = - 6E\text{-}06x^2 + 11.425x + 10854$	$R^2 = 0.9999$
1) x is flow in gpm and y is annual O&M cost in dollars.		

Table A-10. Total Estimated Annual O&M Costs by Tower Type-1st Scenario (1999 Dollars)

Flow (gpm)	Douglas Fir Tower	Redwood Tower	Concrete Tower	Steel Tower	Fiberglass Reinforced Plastic Tower
2000	$32,000	$31,000	$31,000	$32,000	$26,000
4000	$63,000	$61,000	$60,000	$63,000	$51,000
7000	$109,000	$106,000	$103,000	$109,000	$87,000
9000	$140,000	$135,000	$131,000	$139,000	$112,000
11,000	$170,000	$164,000	$159,000	$168,000	$135,000
13,000	$200,000	$193,000	$187,000	$198,000	$159,000
15,000	$230,000	$222,000	$214,000	$228,000	$183,000
17,000	$260,000	$251,000	$242,000	$257,000	$207,000
18,000	$275,000	$265,000	$256,000	$271,000	$218,000
22,000	$327,000	$316,000	$304,000	$323,000	$260,000
25,000	$371,000	$357,000	$344,000	$365,000	$295,000
28,000	$414,000	$399,000	$383,000	$408,000	$329,000
29,000	$429,000	$413,000	$396,000	$422,000	$340,000
31,000	$458,000	$441,000	$423,000	$450,000	$363,000
34,000	$501,000	$482,000	$462,000	$492,000	$397,000
36,000	$530,000	$510,000	$488,000	$520,000	$419,000
45,000	$644,000	$620,000	$593,000	$631,000	$510,000
47,000	$672,000	$646,000	$618,000	$659,000	$532,000
56,000	$798,000	$767,000	$732,000	$780,000	$631,000
63,000	$895,000	$860,000	$821,000	$875,000	$707,000
67,000	$951,000	$913,000	$871,000	$929,000	$750,000
73,000	$1,034,000	$992,000	$946,000	$1,009,000	$815,000
79,000	$1,092,000	$1,048,000	$999,000	$1,065,000	$863,000
94,000	$1,294,000	$1,241,000	$1,182,000	$1,260,000	$1,022,000
102,000	$1,401,000	$1,344,000	$1,279,000	$1,364,000	$1,106,000
112,000	$1,535,000	$1,472,000	$1,399,000	$1,494,000	$1,211,000
146,000	$1,989,000	$1,905,000	$1,807,000	$1,931,000	$1,565,000
157,000	$2,087,000	$1,999,000	$1,897,000	$2,026,000	$1,647,000
204,000	$2,633,000	$2,522,000	$2,389,000	$2,551,000	$2,082,000

Table A-11. Total Annual O&M Cost Equations - 1st scenario for Douglas Fir with Various Features

Type of Tower	O&M Cost Equations[1]	Correlation Coefficient
Non-Fouling Film Fill tower	$y = -8E\text{-}06x^2 + 14.619x + 12191$	$R^2 = 0.9999$
Noise reduction (10dBA)	$y = -1E\text{-}05x^2 + 17.434x + 15301$	$R^2 = 0.9998$
Hybrid tower (Plume Aabatement 32DBT)	$y = -3E\text{-}05x^2 + 35.199x + 46043$	$R^2 = 0.9997$
Splash Fill tower	$y = -1E\text{-}05x^2 + 15.351x + 17751$	$R^2 = 0.9998$
Dry/wet tower	$y = -4E\text{-}05x^2 + 44.021x + 65444$	$R^2 = 0.9997$
1) x is flow in gpm and y is annual O&M cost in dollars.		

Table A-12. Total Estimated Annual O&M Costs - 1st scenario for Douglas Fir with Various Features (1999 Dollars)

Flows (gpm)	Splash Fill Tower	Non-Fouling Film Fill Tower	Hybrid Tower (Plume abatement (32DBT	Dry/Wet Tower	Noise Reduction (10dBA)
2000	$36,000	$33,000	$83,000	$107,000	$39,000
4000	$70,000	$64,000	$162,000	$207,000	$77,000
7000	$120,000	$111,000	$278,000	$353,000	$132,000
9000	$152,000	$141,000	$354,000	$449,000	$169,000
11,000	$185,000	$172,000	$429,000	$542,000	$206,000
13,000	$217,000	$202,000	$504,000	$638,000	$242,000
15,000	$249,000	$233,000	$578,000	$731,000	$278,000
17,000	$281,000	$263,000	$652,000	$823,000	$314,000
18,000	$297,000	$278,000	$688,000	$869,000	$332,000
22,000	$352,000	$331,000	$810,000	$1,021,000	$395,000
25,000	$398,000	$374,000	$916,000	$1,153,000	$447,000
28,000	$444,000	$418,000	$1,021,000	$1,285,000	$499,000
29,000	$459,000	$433,000	$1,056,000	$1,328,000	$516,000
31,000	$490,000	$462,000	$1,126,000	$1,415,000	$551,000
34,000	$535,000	$505,000	$1,230,000	$1,545,000	$603,000
36,000	$566,000	$534,000	$1,299,000	$1,632,000	$637,000
45,000	$685,000	$649,000	$1,561,000	$1,956,000	$773,000
47,000	$714,000	$677,000	$1,628,000	$2,038,000	$806,000
56,000	$845,000	$803,000	$1,925,000	$2,408,000	$956,000
63,000	$946,000	$901,000	$2,155,000	$2,693,000	$1,072,000
67,000	$1,004,000	$957,000	$2,285,000	$2,855,000	$1,138,000
73,000	$1,090,000	$1,040,000	$2,481,000	$3,097,000	$1,238,000
79,000	$1,149,000	$1,098,000	$2,595,000	$3,234,000	$1,304,000
94,000	$1,358,000	$1,301,000	$3,064,000	$3,814,000	$1,544,000
102,000	$1,469,000	$1,408,000	$3,313,000	$4,121,000	$1,672,000
112,000	$1,607,000	$1,543,000	$3,623,000	$4,504,000	$1,831,000
146,000	$2,072,000	$1,997,000	$4,668,000	$5,791,000	$2,370,000
157,000	$2,170,000	$2,095,000	$4,849,000	$6,004,000	$2,480,000
204,000	$2,725,000	$2,641,000	$6,029,000	$7,440,000	$3,118,000

Table A-13. Total Annual O&M Cost - 2nd Scenario for Douglas Fir Tower[1]

Type of Tower	O&M Cost Equations	Correlation Coefficient
Douglas Fir	$y = -8E\text{-}06x^2 + 40.899x + 12191$	$R^2 = 1$
Non-Fouling Film Fill tower	$y = -8E\text{-}06x^2 + 40.899x + 12191$	$R^2 = 1$
Noise reduction (10dBA)	$y = -1E\text{-}05x^2 + 43.714x + 15301$	$R^2 = 1$
Hybrid tower (Plume abatement 32DBT)	$y = -3E\text{-}05x^2 + 61.479x + 46043$	$R^2 = 0.9999$
Splash Fill tower	$y = -8E\text{-}06x^2 + 40.899x + 12191$	$R^2 = 1$
Dry/wet tower	$y = -4E\text{-}05x^2 + 70.301x + 65444$	$R^2 = 0.9999$
1) x is flow in gpm and y is annual O&M cost in dollars.		

Table A-14. Total Estimated Annual O&M Costs - 2nd Scenario for Douglas Fir with Various Features (1999 Dollars)

Flow (gpm)	Douglas Fir Tower	Splash Fill Tower	Non-Fouling Film Fill Tower	Hybrid Tower (Plume Abatement 32DBT)	Dry/wet Tower	Noise Reduction (10dBA)
2000	$84,672	$88,421	$85,206	$135,970	$159,257	$91,561
4000	$168,372	$174,901	$169,319	$267,570	$312,140	$181,974
7000	$293,279	$303,745	$294,678	$462,072	$537,351	$316,399
9000	$376,280	$388,973	$378,007	$590,527	$685,646	$405,835
11,000	$459,125	$474,099	$460,986	$718,275	$832,912	$494,860
13,000	$541,841	$558,817	$543,995	$845,447	$979,338	$583,898
15,000	$624,449	$643,517	$626,883	$972,133	$1,125,053	$672,594
17,000	$706,964	$728,047	$709,666	$1,098,396	$1,270,154	$761,161
18,000	$748,190	$770,082	$750,936	$1,161,386	$1,342,391	$805,589
22,000	$905,604	$930,341	$908,666	$1,388,515	$1,599,431	$972,762
25,000	$1,028,013	$1,055,274	$1,031,492	$1,573,034	$1,810,366	$1,103,982
28,000	$1,150,300	$1,179,986	$1,154,011	$1,757,002	$2,020,500	$1,234,846
29,000	$1,191,038	$1,221,568	$1,194,766	$1,818,081	$2,090,451	$1,278,494
31,000	$1,272,478	$1,304,502	$1,276,408	$1,940,480	$2,229,919	$1,365,743
34,000	$1,394,558	$1,428,840	$1,398,694	$2,123,316	$2,438,898	$1,496,320
36,000	$1,475,894	$1,511,586	$1,480,218	$2,245,244	$2,577,681	$1,583,424
45,000	$1,826,903	$1,867,428	$1,831,779	$2,743,844	$3,138,384	$1,955,315
47,000	$1,907,431	$1,949,225	$1,912,460	$2,862,708	$3,273,483	$2,041,285
56,000	$2,269,476	$2,316,640	$2,275,073	$3,396,505	$3,879,269	$2,427,781
63,000	$2,550,734	$2,601,793	$2,556,715	$3,810,271	$4,348,257	$2,727,946
67,000	$2,711,337	$2,764,574	$2,717,406	$4,045,967	$4,615,488	$2,899,256
73,000	$2,952,096	$3,008,485	$2,958,525	$4,399,241	$5,015,381	$3,156,020
79,000	$3,167,646	$3,224,878	$3,174,080	$4,670,799	$5,309,877	$3,379,633
94,000	$3,763,946	$3,827,964	$3,770,999	$5,534,483	$6,284,310	$4,014,230
102,000	$4,081,655	$4,149,090	$4,089,043	$5,993,799	$6,801,899	$4,352,134
112,000	$4,478,515	$4,549,882	$4,486,287	$6,566,558	$7,446,974	$4,774,262
146,000	$5,825,861	$5,909,142	$5,834,379	$8,505,005	$9,627,677	$6,206,605
157,000	$6,212,680	$6,296,086	$6,221,047	$8,974,854	$10,130,255	$6,605,663
204,000	$7,993,887	$8,085,641	$8,002,509	$11,390,286	$12,801,592	$8,478,752

B.II.b. Using non-surface water sources

A facility may be able to obtain some of its cooling water from a source other than the surface water it is using (WWTP gray water, ground water, or municipal water supply) and thereby reduce the volume of its withdrawals from the surface water and meet the percent of flow requirements. Some facilities may only need to use this alternate source during low flow periods in the surface water source. To use this option, a facility would need to build a pond or basin for the supplemental cooling water.

A facility using gray water may need to install some water treatment equipment (e.g., sedimentation, filtration) to ensure that its discharge of the combined source water and gray water meets any applicable effluent limits. For costing purposes, EPA has assumed that a facility would only need to install treatment for gray water in situations where treatment would have been required for river intake water. Therefore, no additional (i.e., “new”) costs are incurred for treatment of gray water after intake or before discharge.

See the end of this Appendix for cost curves and equations for estimating gray water and municipal water costs.

B.III. Reducing Design Intake Velocity

B.III.a. Passive screens

Passive screens, typically made of wedge wire, are screens that use little or no mechanical activity to prevent debris and aquatic organisms from entering a cooling water intake. The screens reduce impingement and entrainment by using a small mesh size for the wedge wire and a low through-slot velocity that is quickly dissipated. The main components of a passive screening system are typically the screen(s), framing, an air backwash system if needed, and possibly guide rails depending on the installation location.

Passive screens vary in shape and form and include flat panels, curved panels, tee screens, vee screens, and cylinder screens. Screen dimensions (width and depth) vary; they are generally made to order with sizing as required by site conditions. Panels can be of any size, while cylinders are generally in the 12” to 96” diameter range. According to industry sources, the main advantages of passive intake systems are:

- They are fish-friendly due to low slot velocities (peak <0.5 fps), and
- They have no moving parts and thus minimal O&M costs.

New passive intake screens have higher capacity (due to higher screen efficiency) than older versions of passive screens. Wedge wire screens are effective in reducing impingement and entrainment as long as a sufficiently small screen slot size is used and ambient currents have enough velocity to move aquatic organisms around the screen and flush debris away.

The key parameters and additional features that are considered in estimating the cost of passive/wedge wire screening systems on CWIS are:

- Size of screen and flow rate (i.e., volume of water used),
- Size of screen slots/openings,
- Screen material,
- Water depth,
- Water quality (debris, biological growth, salinity), and
- Air backwash systems.

The size and material of a screen most affect cost. For larger volumes of cooling water withdrawals, a facility will need to use larger and/or more intake screens. Branched intakes, with a screen on each branch, can be used for large flows. Screen slot size also impacts the size of a screen. A smaller slot opening will result in a larger screen being required to keep the peak slot velocity under 0.5 fps.

Site-specific conditions significantly affect costs of the screen(s). The water depth affects equipment and installation costs because structural reinforcement is required as depth increases, air backwash system capacities need to be increased due to the reduced air volume at greater depths, and installation is generally more difficult. The potential for clogging from debris and fouling from biogrowth are water quality concerns that affect costs. The amount and type of debris influence the size of openings in the screen, which affects water flow through the screen and thus screen size. Finer debris may require a smaller slot opening to prevent debris from entering and clogging the openings.

Generally, speed and flow of water do not affect the installation cost or the operation of passive intakes, however there must be adequate current in the source water to carry away debris that is backwashed from the screen so that it does not become (re)clogged. It is recommended as good engineering practice that the axis of the screen cylinder be oriented parallel with the water flow to minimize fish entrainment and to aid in removal of debris during air backwash. The effects of the presence of sensitive species or certain types of species affect the design of the screen and may increase screen cost. For example, the lesser strength of a local species could result in the need for a peak velocity less than 0.5 fps which would result in a larger screen. Biofouling from the attachment of zebra mussels and barnacles and the growth of algae may necessitate the use of a special screen material, periodic flushing with biocides, and in limited cases, manual cleaning by divers. For example, the presence of zebra mussels often requires the use of a special alloy material to prevent attachment to the screen assembly.

The level of debris in the water also affects whether an air backwash system is needed and how often it is used. Heavy debris loadings may dictate the need for more frequent air backwashing. If the air backwash frequency is high enough, a larger compressor may be required to recharge the accumulator tank more quickly.

Another water quality factor that affects screen cost is water corrosiveness (e.g., whether the intake water is seawater, freshwater, or brackish). Most passive screens are manufactured in either 304 or 316 stainless steel for freshwater installations. The 316L stainless steel can be used for some saltwater installations, but has limited life. Screens made of copper-nickel alloys (70/30 or 90/10) have shown excellent corrosion resistance in saltwater, however they are significantly more expensive than stainless steel (50% to 100% greater in cost, i.e., can be double the cost).

Installation

The screen installation cost is largely a function of site conditions. Costs are typically greater for deeper installations and larger screens (e.g., screens for larger volumes of flow). Site-specific conditions such as space constraints, environmental and license/permit requirements, and the location/accessibility of the intake may greatly affect installation cost. For instance, for a project requiring dredging the installation cost can be two to four more times the installation cost of a project that does not require dredging. However, for National cost estimates, atypical conditions will not be considered in the cost estimates.

Capital Costs

EPA assumed that the capital cost of passive screens will be 60% of the capital cost of a basic traveling screen of similar size (Table A-24a). This assumption is based on discussions with industry representatives. The lower capital cost is because passive screen systems have lower onshore site preparation and installation costs (no extensive mechanical equipment as in the traveling screens) and are easier to install in offshore situations. The estimated capital costs for passive screens are shown in Table A-15, corresponding to the flows shown in Table A-19b for a through screen velocity of 0.5 fps. Passive screens for sizes larger than those shown in Table A-15 will generate flows higher than 50,000 gpm. For flows greater than 50,000 gpm, particularly when water is drawn in from a river, the size of the CWIS site becomes very big and the necessary network fanning for intake points and screens generally makes passive screen systems unfeasible.

Table A-15. Estimated Capital Costs for a Through Flow Passive Water Screen Stainless Steel 304 - Standard Design[1] (1999 Dollars)

Well Depth (ft)	Screen Panel Width (ft)			
	2	5	10	14
10	$34,200	$56,100	$91,800	$128,700
25	$49,800	$84,900	$140,400	(2)
50	$74,400	$122,700	(2)	(2)
75	$99,000	(2)	(2)	(2)
100	$135,600	(2)	(2)	(2)

1) Cost estimate includes stainless steel 304 structure.
2) Not estimated because passive screen systems of this size are not feasible.

As noted above, the capital costs for special screen materials (e.g., copper-nickel alloys) are typically 50% to 100% higher.

Table A-16 presents cost equations for estimating capital costs for passive screens. The "x" in the equation represents the flow volume in gpm and the "y" value is the passive screen total capital cost. Cost equations associated with a flow of 1 fps are provided for comparative purposes.

Table A-16. Capital Cost Equations for Passive Screens

Screen Width (ft)	Passive Screens Velocity 0.5 ft/sec		Passive Screens Velocity 1ft/sec	
	Equation[1]	Correlation Coefficient	Equation[1]	Correlation Coefficient
2	$y = 3E\text{-}08x^3 - 0.0008x^2 + 12.535x + 11263$	$R^2 = 0.9991$	$y = 2E\text{-}12x^4 - 1E\text{-}07x^3 + 0.0029x^2 - 18.885x + 71766$	$R^2 = 1$
5	$y = 0.0002x^2 + 1.5923x + 47041$	$R^2 = 1$	$y = 4E\text{-}05x^2 + 1.0565x + 43564$	$R^2 = 1$
10	$y = 3.7385x + 58154$	$R^2 = 1$	$y = 1.8x + 59400$	$R^2 = 1$

1) x is the flow in gpm y is the capital cost in dollars.

The typical useful life of a passive screen is greater than 20 years. See the end of this Appendix for cost curves and equations.

Operation and Maintenance (O&M) Costs for Passive Screens

Generally, there are no appreciable O&M costs for passive screens unless there are biofouling problems or zebra mussels in the environment. Biofouling problems can be remedied through the proper choice of materials and periodic mechanical cleaning. Screens equipped with air backwash systems require periodic compressor/motor/valve maintenance.

B.III.b. Velocity Caps

The cost driver of velocity caps is the installation cost. Installation is carried out underwater where the water intake mouth is modified to fit the velocity cap over the intake. EPA estimated capital costs for velocity caps based on the following assumptions:

- Four velocity caps can be installed in a day,
- Cost of the installation crew is similar to the cost of the water screen installation crew (see Box A-2),

- To account for the difficulty in installing in deep water, an additional work day is assumed for every increase in depth size category, and
- Equipment cost for a velocity cap is assumed to be 25% of the velocity cap installation cost. In our BPJ, this is a conservatively high estimate of the cost of velocity cap material and delivery to the installation site.

Based on these assumptions, EPA calculated estimated costs for velocity caps, which are shown in Tables A-17a and A-17b. EPA calculated the number of velocity caps needed for various flow sizes based on a flow velocity of 0.5ft/sec and assuming that the intake area to be covered by the velocity cap is 20 ft^2 which is the area comparable to a pipe diameter of about 5 feet. For flows requiring pipes larger than this, EPA assumed, for velocity cap costing purposes, that multiple intake pipes with a standard, easy-to-handle pipe diameter will be used rather than larger-diameter, custom made pipes (based on BPJ). Table A-17a presents the calculated velocity cap installation costs while Table A-17b presents the calculated total capital costs of velocity caps including installation and equipment. Cost equations for estimating the total capital costs of velocity caps are presented in Table A-18. Cost curves and equations are at the end of the Appendix.

Table A-17a. Estimated Velocity Cap Installation Costs (1999 Dollars)

Flow (gpm) (No. of velocity caps)	Water Depth (ft)				
	8	20	30	50	65
Up to 18,000 (4 VC)	$8000	$12,500	$17,000	$21,500	$26,000
18,000 ≤ flow <35,000 (9 VC)	$12,500	$17,000	$21,500	$26,000	$30,500
35,000≤ flow <70,000 (15 VC)	$21,500	$26,000	$30,500	$35,000	$39,500
70,000≤ flow <100,000 (23 VC)	$30,500	$35,000	$39,500	$44,000	$48,500
157,000 (35 VC)	$44,000	$48,500	$53,000	$57,500	$62,000
204,000 (46 VC)	$57,500	$62,000	$66,500	$71,000	$75,500

Table A-17b. Estimated Velocity Cap Equipment and Installation Costs (1999 Dollars)

Flow (gpm) (No. of velocity caps)	Water Depth (ft)				
	8	20	30	50	65
Up to 18,000 (4 VC)	$10,000	$15,625	$21,250	$26,875	$32,500
18,000 ≤ flow <35,000 (9 VC)	$15,625	$21,250	$26,875	$32,500	$38,125
35,000≤ flow <70,000 (15 VC)	$26,875	$32,500	$38,125	$43,750	$49,375
70,000≤ flow <100,000 (23 VC)	$38,125	$43,750	$49,375	$55,000	$60,625
157,000 (35 VC)	$55,000	$60,625	$66,250	$71,875	$77,500
204,000 (46 VC)	$71,875	$77,500	$83,125	$88,750	$94,375

Table A-18. Cost Equations for Velocity Cap Capital Costs

Flow (gpm) (No. of velocity caps)	Velocity Cap Capital Cost Equation	Correlation Coefficient
Up to 18,000 (4 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 4212.7$	$R^2 = 0.9962$
18,000 $\leq$ flow <35,000 (8 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 9837.7$	$R^2 = 0.9962$
35,000$\leq$ flow <70,000 (16 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 21088$	$R^2 = 0.9962$
70,000$\leq$ flow <100,000 (24 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 32338$	$R^2 = 0.9962$
157,000 (35 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 49213$	$R^2 = 0.9962$
204,000 (46 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 66088$	$R^2 = 0.9962$
1) x represents the water depth in feet and y is the capital cost in dollars.		

B.III.c. Branching the intake pipe to increase the number of openings or widening the intake pipe

Branching an intake pipe involves the use of fittings to attach the separate pipe sections. See the end of this Appendix for costs curves and equations.

B.IV. Implementing Other Design and Construction Technologies to Reduce Damage from I&E

B.IV.a. Installation of traveling screens with fish baskets

Single-entry, single-exit vertical traveling screens (conventional traveling screens) contain a series of wire mesh screen panels that are mounted end to end on a band to form a vertical loop. As water flows through the panels, debris and fish that are larger than the screen openings are caught on the screen or at the base of each panel in a basket. As the screen rotates around, each panel in turn reaches a top area where a high-pressure jet spray wash pushes debris and fish from the basket into a trash trough for disposal. As the screen rotates over time, the clean panels move down, back into the water to screen the intake flow.

Conventional traveling screens can be operated continuously or intermittently. However, when these screens are fitted with fish baskets (also called modified conventional traveling screens or Ristroph screens), the screens must be operated continuously so that fish that are collected in the fish baskets can be released to a bypass/return using a low pressure spray wash when the basket reaches the top of the screen. Once the fish have been removed, a high pressure jet spray wash is typically used to remove debris from the screen. In recent years, the design of fish baskets has been refined (e.g., deeper baskets, smoother mesh, better balance) to decrease chances of injury and mortality and to better retain fish (i.e., prevent them from flopping out and potentially being injured). Methods used to protect fish include the Stabilized Integral Marine Protective Lifting Environment (S.I.M.P.L.E.) developed by Brackett Green and the Modified Ristroph design by U.S. Filter.

U.S. Filter's conventional (through flow) traveling screens are typically manufactured in widths ranging from two feet to at least 14 feet, for channel depths of up to 100 feet, although custom design is possible to fit other dimensions.

Flow

To calculate the flow through a screen panel, the width of the screen panel is multiplied by the water depth and, using the desired flow velocities (1 foot per second and 0.5 foot per second), is converted to gallons per minute assuming a screen efficiency of 50%. The calculated flows for selected screen widths, water depths, and well depths are presented in Tables A-19a and A-19b. For flows greater than this, a facility would generally install multiple screens or use a custom design.

Well depth includes the height of the structure above the water line. The well depth can be more than the water depth by a few to tens of feet. The flow velocities used are representative of a flow speed that is generally considered to be fish friendly particularly for sensitive species (0.5 fps), and a flow speed that may be more practical for some facilities to achieve but typically provides less fish protection. The water depths and well depths are approximate and may vary based on actual site conditions.

Table A-19a. Average Flow Through A Traveling Water Screen (gpm) for a Flow Velocity of 1.0 fps

Well Depth (ft)	Water Depth (ft)	Basket Panel Screening Width (ft)			
		2	5	10	14
10	8	4000	9000	18,000	25,000
25	20	9000	22,000	45,000	63,000
50	30	13,000	34,000	67,000	94,000
75	50	22,000	56,000	112,000	157,000
100	65	29,000	73,000	146,000	204,000

Table A-19b. Average Flow Through A Traveling Water Screen (gpm) for a Flow Velocity of 0.5 fps

Well Depth (ft)	Water Depth (ft)	Basket Screening Panel Width			
		2	5	10	14
10	8	2000	4000	9000	13,000
25	20	4000	11,000	22,000	31,000
50	30	7000	17,000	34,000	47,000
75	50	11,000	28,000	56,000	79,000
100	65	15,000	36,000	73,000	102,000

Capital Costs

Equipment Cost

Basic costs for screens with flows comparable to those shown in the above tables are presented in Tables A-20a and A-20b. Table A-20a contains estimated costs for basic traveling screens without fish handling features, that have a carbon steel structure coated with epoxy paint. The cost of similar size screens using 316 stainless steel is generally twice as expensive. The advantages of using 316 stainless steel are its longer useful life and its resistance to harsh water quality conditions. The costs presented in Table A-20b are for traveling screens with fish handling features including a spray system, a fish trough, housings and transitions, continuous operating features, a drive unit, frame seals, and engineering. Installation costs and spray pump costs are presented separately below.

Table A-20a. Estimated Equipment Cost for Traveling Water Screens Without Fish Handling Features[1] (1999 Dollars)

Well Depth (ft)	Basket Screening Panel Width (ft)			
	2	5	10	14
10	$30,000	$35,000	$45,000	$65,000
25	$35,000	$45,000	$60,000	$105,000
50	$55,000	$70,000	$105,000	$145,000
75	$75,000	$100,000	$130,000	$175,000
100	$115,000	$130,000	$155,000	$200,000

1) Cost includes carbon steel structure coated with epoxy paint and non-metallic trash baskets with Type 304 stainless mesh and intermittent operation components.

Source: Vendor estimates.

Table A-20b. Estimated Equipment Cost for Traveling Water Screens With Fish Handling Features[1] (1999 Dollars)

Well depth (ft)	Basket Screening Panel Width (ft)			
	2	5	10	14
10	$63,500	$73,500	$94,000	$135,500
25	$81,250	$97,500	$133,000	$214,000
50	$122,500	$152,000	$218,000	$319,500
75	$163,750	$210,000	$283,000	$414,500
100	$225,000	$267,500	$348,000	$504,500

1) Cost includes carbon steel screen structure coated with epoxy paint and non-metallic fish handling panels, spray systems, fish trough, housings and transitions, continuous operating features, drive unit, frame seals, and engineering (averaged over 5 units). Costs do *not* include differential control system, installation, and spray wash pumps.

Source: Vendor estimates.

Installation Cost

Installation costs of traveling screens are based on the following assumptions of a typical average installation requirement for a hypothetical scenario. Site preparation and earth work are calculated based on the following assumptions:

- ***Clearing and grubbing*****:** Clearing light to medium brush up to 4" diameter with a bulldozer.
- ***Earthwork*****:** Excavation of heavy soils. Quantity is based on the assumption that earthwork increases with screen width.
- ***Paving and surfacing*****:** Using concrete 8" thick and assuming that the cost of pavement attributed to screen installation is 6x3 yards for the smallest screen and 25x6 yards for the largest screen.
- ***Structural concrete*****:** The structural concrete work attributed to screen installation is four 12"x12" reinforced concrete columns with depths varying between 1.5 yards and 3 yards. There is more structural concrete work for a water intake structure, however, for new source screens and retrofit screens, only a portion of the intake structural cost can be justifiably attributed to the screen costs. For new screens, most of the concrete structure work is for developing the site to make it accessible for equipment and protect it from hydraulic elements, which are necessary for constructing the intake itself. For retrofits, some of the structural concrete will already exist and some of it will not be needed since the intake is already in place and only the screen needs to be installed. All unit costs used in

calculating on-shore site preparation were obtained from *Heavy Construction Cost Data 1998* (R. S. Means, 1997b).

Table A-21a presents site preparation installation costs that apply to traveling screens both with and without fish handling features. The total onshore construction costs presented in Table A-21a are for a screen to be installed in a 10-foot well depth. Screens to be installed in deeper water are assumed to require additional site preparation work. Hence for costing purposes it is assumed that site preparation costs increase at a rate of an additional 25% per depth factor (calculated as the ratio of the well depth to the base well depth of 10 feet) for well depths greater than 10 feet. Table A-21b presents the estimated costs of site preparation for four sizes of screen widths and various well depths.

Table A-21a. Estimated Installation (Site Preparation) Costs for Traveling Water Screens Installed at a 10-foot Well Depth (1999 Dollars)

Screen Width (ft)	Clearing and Grabbing (acre)	Clearing Cost[1]	Earth Work (cy)	Earth Work Cost[1]	Paving and Surfacing Using Concrete (sy)	Paving Cost[1]	Structural Concrete (cy)	Structural Cost	Total Onshore Construction Costs
2	0.1	$250	200	$17,400	18	$250	0.54	$680	$19,000
5	0.35	$875	500	$43,500	40	$560	0.63	$790	$46,000
10	0.7	$1,750	1000	$87,000	75	$1,050	0.72	$900	$91,000
14	1	$2,500	1400	$121,800	150	$2,100	1.08	$1,350	$128,000

ft = feet, cy=cubic yard, sy=square yard
1) Clearing cost @ $2,500/acre, earth work cost @ $87/cubic yard, paving cost @ $14/square yard, structural cost @ $1,250/cubic yard.

Source of unit costs: *Heavy Construction Cost Data 1998* (R.S. Means, 1997b).

Table A-21b. Estimated Installation (Site Preparation, Construction, and Onshore Installation) Costs for Traveling Water Screens of Various Well Depths (1999 Dollars)

Well Depth (ft)	Screen Panel Width (ft)			
	2	5	10	14
10	$19,000	$46,000	$91,000	$128,000
25	$31,000	$75,000	$148,000	$208,000
50	$43,000	$104,000	$205,000	$288,000
75	$55,000	$132,000	$262,000	$368,000
100	$67,000	$161,000	$319,000	$448,000

Source: R.S. Means (1997b) and vendor estimates.

EPA developed a hypothetical scenario of a typical underwater installation to estimate an average cost for underwater installation costs. EPA estimated costs of personnel and equipment per day, as well as mobilization and demobilization. Personnel and equipment costs would increase proportionately based on the number of days of a project, however mobilization and demobilization costs would be relatively constant regardless of the number of days of a project since the cost of transporting personnel and equipment is largely independent of the length of a project. The hypothetical project scenario and estimated costs are presented in Box A-2. This scenario uses passive intake screens, but the estimated costs can be used to develop installation costs for traveling screens and velocity caps.

As shown in the hypothetical scenario in Box A-2, the estimated cost for a one-day installation project would be $8,000 ($4,500 for personnel and equipment, plus $3,500 for mobilization and demobilization). Using this one-day cost estimate as a basis, EPA generated estimated installation costs for various sizes of screens under different scenarios. These costs are presented in Table A-22. The baseline costs for underwater installation include the costs of a crew of divers and equipment including mobilization and demobilization, divers, a barge, and a crane. The number of days needed is based on a minimum of one day for a screen of less than 5 feet in width and up to 10 feet in well depth. Using best professional judgement (BPJ), EPA estimated the costs for larger jobs assuming an increase of two days for every increase in well depth size and of one day for every increase in screen width size.

Box A-2. Hypothetical Scenario for Underwater Installation of an Intake Screen System

This project involves the installation of 12, t-24 passive intake screens onto a manifold inlet system. Site conditions include a 20-foot water depth, zero to one-foot underwater visibility, 60-70 °F water temperature, and fresh water at an inland. The installation is assumed to be 75 yards offshore and requires the use of a barge or vessel with 4-point anchor capability and crane.

Job Description:
Position and connect water intake screens to inlet flange via 16 bolt/nut connectors. Lift, lower, and position intake screens via crane anchored to barge or vessel. Between 4 and 6 screens of the smallest size can be installed per day per dive team, depending on favorable environmental conditions.

Estimated Personnel Costs:
Each dive team consists of 5 people (1 supervisor, 2 surface tenders, and 2 divers), the assumed minimum number of personnel needed to operate safely and efficiently. The labor rates are based on a 12-hour work day. The day rate for the supervisor is $600. The day rate for each diver is $400. The day rate for each surface tender is $200. Total base day rate per dive team is $1,800.

Estimated Equipment Costs:
Use of hydraulic lifts, underwater impact tools, and other support equipment is $450 per day. Shallow water air packs and hoses cost $100 per day. The use of a crane sufficient to lift the 375 lb t-24 intakes is $300 per day. A barge or vessel with 4-point anchor capability can be provided by either a local contractor or the dive company for $1,800 per day (cost generally ranges from $1,500-$2,000 per day). This price includes barge/vessel personnel (captain, crew, etc) but the barge/vessel price does not include any land/waterway transportation needed to move barge/vessel to inland locations. Using land-based crane and dive operations can eliminate the barge/vessel costs. Thus total equipment cost is $2,650 per day.

Estimated Mobilization and Demobilization Expenses:
This includes transportation of all personnel and equipment to the job site via means necessary (air, land, sea), all hotels, meals, and ground transportation. An accurate estimate on travel can vary wildly depending on job location and travel mode. For this hypothetical scenario, costs are estimated for transportation with airfare, and boarding and freight and would be $3,500 for the team (costs generally range between $3,000 and $4,000 for a team).

Other Considerations:
Uncontrollable factors like weather, water temperature, water depth, underwater visibility, currents, and distance to shore can affect the daily production of the dive team. These variables always have to be considered when a job is quoted on a daily rate. Normally, the dive-company takes on the risks for these variables because the job is quoted on a "to completion" status. These types of jobs usually take a week or more for medium to large-size installations.

Total of Estimated Costs:
The final estimated total for this hypothetical job is nearly $4500 per day for personnel and equipment. For a three-day job, this would total about $13,500. Adding to this amount about $3,500 for mobilization and demobilization, the complete job is estimated at $17,000.

Note: Costs for a given project vary greatly depending on screen size, depth of water, and other site-specific conditions such as climate and site accessibility.

Source: Developed based on information from Paroby (1999).

Table A-22. Estimated Underwater Installation Costs for Various Screen Widths and Well Depths[1] (1999 Dollars)

Well Depth (ft)	Basket Screening Panel Width			
	2	5	10	14
10	$8,000	$12,500	$17,000	$21,500
25	$17,000	$21,500	$26,000	$30,500
50	$26,000	$30,500	$35,000	$39,500
75	$35,000	$39,500	$44,000	$48,500
100	$44,000	$48,500	$53,000	$57,500

1) Based on hypothetical scenario of crew and equipment costs of $4,500 per day and mobilization and demobilization costs of $3,500 (see Box A-2).

Table A-23 presents total estimated installation costs for traveling screens. These costs equal the total of the costs in Table A-21b and Table A-22. Installation costs for traveling screens with fish handling features and those without fish handling features are assumed to be similar.

Table A-23. Estimated Total Installation Costs for Traveling Water Screens[1] (1999 Dollars)

Well Depth (ft)	Basket Screening Panel Width (ft)			
	2	5	10	14
10	$27,000	$58,500	$108,000	$149,500
25	$48,000	$96,500	$174,000	$238,500
50	$69,000	$134,500	$240,000	$327,500
75	$90,000	$171,500	$306,000	$416,500
100	$111,000	$209,500	$372,000	$505,500

1) Includes site preparation, and onshore and underwater construction and installation costs.

Total Estimated Capital Costs

The installation costs in Table A-23 can be added to the equipment costs in Tables A-20a and A-20b to derive total equipment and installation costs for traveling screens with and without fish handling features. These estimated costs are presented in Tables A-24a and A-24b. The flow volume corresponding to each screen width and well depth combination varies based on the through screen flow velocity. These flow volumes were presented in Tables A-19a and A-19b for flow velocities of 1.0 fps and 0.5 fps, respectively.

Table A-24a. Estimated Total Capital Costs for Traveling Screens Without Fish Handling Features (Equipment and Installation)[1] (1999 Dollars)

Well Depth (ft)	Screening Basket Panel Width (ft)			
	2	5	10	14
10	$57,000	$93,500	$153,000	$214,500
25	$83,000	$141,500	$234,000	$343,500
50	$124,000	$204,500	$345,000	$472,500
75	$165,000	$271,500	$436,000	$591,500
100	$226,000	$339,500	$527,000	$705,500

1) Costs include carbon steel structure coated with an epoxy paint, non-metallic trash baskets with Type 304 stainless mesh, and intermittent operation components and installation.

Table A-24b. Estimated Total Capital Costs for Traveling Screens With Fish Handling Features (Equipment and Installation)[1] (1999 Dollars)

Well Depth (ft)	Screening Basket Panel Width (ft)			
	2	5	10	14
10	$90,500	$132,000	$202,000	$285,000
25	$129,250	$194,000	$307,000	$453,000
50	$191,500	$287,000	$458,000	$647,000
75	$253,750	$381,500	$589,000	$831,000
100	$336,000	$477,000	$720,000	$1,010,000

1) Costs include non-metallic fish handling panels, spray systems, fish trough, housings and transitions, continuous operating features, drive unit, frame seals, engineering (averaged over 5 units), and installation. Costs do *not* include differential control system and spray wash pumps.

Tables A-25a and A-25b present equations that can be used to estimate costs for traveling screens at 0.5 fps and 1.0 fps, respectively. See the end of this Appendix for cost curves and equations.

Table A-25a. Capital Cost Equations for Traveling Screens for Velocity of 0.5 fps

Screen Width (ft)	Traveling Screens with Fish Handling Equipment		Traveling Screens without Fish Handling Equipment	
	Equation[1]	Correlation Coefficient	Equation[1]	Correlation Coefficient
2	$y = 2E\text{-}11x^4 - 6E\text{-}07x^3 + 0.0053x^2 + 1.0283x + 71506$	$R^2 = 1$	$y = 1E\text{-}11x^4 - 4E\text{-}07x^3 + 0.0036x^2 + 0.8119x + 44000$	$R^2 = 1$
5	$y = 2E\text{-}12x^4 - 2E\text{-}07x^3 + 0.004x^2 - 27.772x + 187917$	$R^2 = 1$	$y = 1E\text{-}12x^4 - 9E\text{-}08x^3 + 0.0024x^2 - 14.878x + 120042$	$R^2 = 1$
10	$y = 2E\text{-}13x^4 - 3E\text{-}08x^3 + 0.0017x^2 - 22.739x + 293474$	$R^2 = 1$	$y = 1E\text{-}13x^4 - 2E\text{-}08x^3 + 0.0012x^2 - 15.939x + 214636$	$R^2 = 1$
14	$y = 6E\text{-}14x^4 - 1E\text{-}08x^3 + 0.001x^2 - 15.915x + 353385$	$R^2 = 1$	$y = 4E\text{-}14x^4 - 8E\text{-}09x^3 + 0.0006x^2 - 6.4565x + 222007$	$R^2 = 1$

1) x is the flow in gpm y is the capital cost in dollars.

Table A-25b. Capital Cost Equations for Traveling Screens for Velocity of 1 fps

Screen Width (ft)	Traveling Screens with Fish Handling Equipment		Traveling Screens without Fish Handling Equipment	
	Equation[1]	Correlation Coefficient	Equation[1]	Correlation Coefficient
2	$y = 5E\text{-}12x^4 - 3E\text{-}07x^3 + 0.0072x^2 - 47.584x + 185604$	$R^2 = 1$	$y = 4E\text{-}12x^4 - 2E\text{-}07x^3 + 0.0048x^2 - 31.475x + 119611$	$R^2 = 1$
5	$y = 1E\text{-}13x^4 - 2E\text{-}08x^3 + 0.001x^2 - 13.641x + 187644$	$R^2 = 1$	$y = 7E\text{-}14x^4 - 1E\text{-}08x^3 + 0.0006x^2 - 6.9771x + 117069$	$R^2 = 1$
10	$y = 2E\text{-}14x^4 - 5E\text{-}09x^3 + 0.0005x^2 - 15.877x + 344095$	$R^2 = 1$	$y = 1E\text{-}14x^4 - 4E\text{-}09x^3 + 0.0004x^2 - 11.291x + 251956$	$R^2 = 1$
14	$y = 4E\text{-}15x^4 - 2E\text{-}09x^3 + 0.0003x^2 - 9.9356x + 387337$	$R^2 = 1$	$y = 3E\text{-}15x^4 - 1E\text{-}09x^3 + 0.0002x^2 - 4.6948x + 248170$	$R^2 = 1$
1) x is the flow in gpm y is the capital cost in dollars.				

Potential Additional Capital Costs

Fish spray pumps are used to increase the survival rate of fish by directing the fish out of fish baskets and facilitating their return to the waterbody. In some instances, water used for spraying fish can be obtained by passing a portion of the water pumped for cooling to use in spraying fish. These pumps are an additional cost that is minimal compared to the other equipment and installation costs of a CWIS. They are presented separately to account for systems that must have a separate pumping facility for fish spraying. Assuming that a minimum of one percent of the flows used in cooling is used in spraying fish will yield a flow range from 20 gpm to 2250 gpm. Even if the one percent flow assumption varies for some systems, the flow range generated based on the one percent assumption is large enough to construct a cost curve for water pumps. Table A-26 presents the estimated costs of fish spray pumps, calculated based on the R.S. Means cost data for centrifugal water pumps (R.S. Means, 1997c). The costs in Table A-26 include labor, material, and equipment. See the end of this Appendix for cost curves and equations.

Table A-26. Estimated Total Capital Costs for Fish Spray Pumps (1999 Dollars)

Centrifugal Pump Flow (gpm)	Total Capital Costs for Centrifugal Pumps	Cost Equation[1]	Correlation Coefficient
10	$ 800	$y = -0.2394x^2 + 47.9x + 364.04$	$R^2 = 0.9907$
50	$ 2250		
75	$ 2500		
100	$ 2800		
500	$ 3700	$y = 2E\text{-}06x^3 - 0.0035x^2 + 3.8696x + 2446.8$	$R^2 = 1$
1000	$ 4400		
2000	$ 9000		
1) x is flow in gpm and y is cost in dollars.			

Operation and Maintenance (O&M) Costs for Traveling Screens

O&M costs for traveling screens vary by type, size, and mode of operation of the screen. Based on discussions with industry representatives, EPA estimated annual O&M cost as a percentage of total capital cost. The O&M cost factor ranges between 8% of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5% for the largest traveling screen since O&M costs do not increase proportionately with screen size. Estimated annual O&M costs for traveling screens with and without fish handling features are presented in Tables A-27a and A-27b, respectively. As noted earlier, the flow volume corresponding to each screen width and well depth combination varies based on the through screen flow velocity. These flow volumes were presented in Tables A-19a and A-19b for flow velocities of 1.0 fps and 0.5 fps, respectively.

Table A-27a. Estimated Annual O&M Costs for Traveling Water Screens Without Fish Handling Features (Carbon Steel - Standard Design)[1] (1999 Dollars)

Well Depth (ft)	Screen Panel Width (ft)			
	2	5	10	14
10	$4560	$6545	$7650	$12,870
25	$5810	$9905	$14,040	$17,175
50	$8680	$12,270	$17,250	$23,625
75	$11,550	$16,290	$21,800	$29,575
100	$13,560	$16,975	$26,350	$35,275
1) Annual O&M costs range between 8% of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5% for the largest traveling screen.				

Table A-27b. Estimated Annual O&M Costs for Traveling Water Screens With Fish Handling Features (Carbon Steel Structure, Non-Metallic Fish Handling Screening Panel)[1] (1999 Dollars)

Well Depth (ft)	Screen Panel Width (ft)			
	2	5	10	14
10	$7240	$9240	$10,100	$17,100
25	$9048	$13,580	$18,420	$22,650
50	$13,405	$17,220	$22,900	$32,350
75	$17,763	$22,890	$29,450	$41,550
100	$20,160	$23,850	$36,000	$50,500
1) Annual O&M costs range between 8% of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5% for the largest traveling screen.				

Tables A-28a and A-28b present O&M cost equations generated from the above tables for various screen sizes and water depths at velocities of 0.5 fps and 1 fps, respectively. The “x” value of the equation is the flow and the ”y” value is the O&M cost in dollars.

Table A-28a. Annual O&M Cost Equations for Traveling Screens Velocity 0.5 fps

Screen Width (ft)	Traveling Screens with Fish Handling Equipment		Traveling Screens without Fish Handling Equipment	
	Equation[1]	Correlation Coefficient	Equation[1]	Correlation Coefficient
2	$y = -3E\text{-}05x^2 + 1.6179x + 3739.1$	$R^2 = 0.9943$	$y = -2E\text{-}05x^2 + 1.0121x + 2392.4$	$R^2 = 0.9965$
5	$y = -1E\text{-}05x^2 + 0.8563x + 5686.3$	$R^2 = 0.9943$	$y = -7E\text{-}06x^2 + 0.6204x + 4045.7$	$R^2 = 0.9956$
10	$y = -2E\text{-}06x^2 + 0.5703x + 5864.4$	$R^2 = 0.9907$	$y = 9E\text{-}11x^3 - 1E\text{-}05x^2 + 0.8216x + 1319.5$	$R^2 = 0.9997$
14	$y = 4E\text{-}15x^4 - 9E\text{-}10x^3 + 7E\text{-}05x^2 - 1.5031x + 26977$	$R^2 = 1$	$y = 2E\text{-}15x^4 - 6E\text{-}10x^3 + 4E\text{-}05x^2 - 0.8552x + 18106$	$R^2 = 1$
1) x is the flow in gpm and y is the annual O&M cost in dollars.				

Table A-28b. Annual O&M Cost Equations for Traveling Screens Velocity 1 fps

Screen Width (ft)	Traveling Screens with Fish Handling Equipment		Traveling Screens without Fish Handling Equipment	
	Equation[1]	Correlation Coefficient	Equation[1]	Correlation Coefficient
2	$y = -8E\text{-}06x^2 + 0.806x + 3646.7$	$R^2 = 0.982$	$y = -4E\text{-}06x^2 + 0.5035x + 2334$	$R^2 = 0.9853$
5	$y = -3E\text{-}06x^2 + 0.4585x + 5080.7$	$R^2 = 0.9954$	$y = -2E\text{-}06x^2 + 0.3312x + 3621.1$	$R^2 = 0.9963$
10	$y = -6E\text{-}07x^2 + 0.2895x + 5705.3$	$R^2 = 0.9915$	$y = 1E\text{-}11x^3 - 3E\text{-}06x^2 + 0.4047x + 1359.4$	$R^2 = 1$
14	$y = 3E\text{-}16x^4 - 1E\text{-}10x^3 + 2E\text{-}05x^2 - 0.8264x + 28092$	$R^2 = 1$	$y = 2E\text{-}16x^4 - 8E\text{-}11x^3 + 1E\text{-}05x^2 - 0.4829x + 18975$	$R^2 = 1$
1) x is the flow in gpm and y is the annual O&M cost in dollars.				

B.IV.b. Adding fish baskets to existing traveling screens

Capital Costs

Table A-29 presents estimated costs of fish handling equipment without installation costs. These estimated costs represent the difference between costs for equipment with fish handling features (Table A-20b) and costs for equipment without fish handling features (Table A-20a), plus a 20% add-on for upgrading existing equipment (mainly to convert traveling screens from intermittent operation to continuous operation).[12] These costs would be used to estimate equipment capital costs for upgrading an existing traveling water screen to add fish protection and fish return equipment.

[12]This 20% additional cost for upgrades to existing equipment was included based on recommendations from one of the equipment vendors supplying cost data for this research effort.

Table A-29. Estimated Capital Costs of Fish Handling Equipment (1999 Dollars)

Well Depth (ft)	Basket Screening Panel Width (ft)			
	2	5	10	14
10	$40,200	$46,200	$58,800	$84,600
25	$55,500	$63,000	$87,600	$131,400
50	$81,000	$99,000	$135,600	$209,400
75	$106,500	$132,000	$183,600	$287,400
100	$132,000	$165,000	$231,600	$365,400

Source: Vendor estimates.

Installation of Fish Handling Features to Existing Traveling Screens

As stated earlier, the basic equipment cost of fish handling features (presented in Table A-29) is calculated based on the difference in cost between screens with and without fish handling equipment, plus a cost factor of 20% for upgrading the existing system from intermittent to continuous operation. Although retrofitting existing screens with fish handling equipment will require upgrading some mechanical equipment, installing fish handling equipment generally will not require the use of a costly barge that is equipped with a crane and requires a minimum number of crew to operate it. EPA assumed that costs are 75% of the underwater installation cost (Table A-22) for a traveling screen (based on BPJ). Table A-30 shows total estimated costs (equipment and installation) for adding fish handling equipment to an existing traveling screen.

Table A-30. Estimated Capital Costs of Fish Handling Equipment and Installation[1] (1999 Dollars)

Well Depth (ft)	Basket Screening Panel Width (ft)			
	2	5	10	14
10	$46,200	$55,575	$71,550	$100,725
25	$68,250	$79,125	$107,100	$154,275
50	$100,500	$121,875	$161,850	$239,025
75	$132,750	$161,625	$216,600	$323,775
100	$165,000	$201,375	$271,350	$408,525

1) Installation portion of the costs estimated as 75% of the *underwater* installation cost for installing a traveling water screen.

The additional O&M costs due to the installation of fish baskets on existing traveling screens can be calculated by subtracting the O&M costs for basic traveling screens from the O&M costs for traveling screens with fish baskets. See the end of this Appendix for cost curves and equations.

B.V. Additional Cost Considerations

To account for other minor cost elements, EPA estimates that 5% may need to be added to the total cost for each alteration. Minor cost elements include:

- Permanent buoys for shallow waters to warn fishing boats and other boats against dropping anchor over the pipes. Temporary buoys and warning signs during construction.

- Additional permit costs. Permit costs may increase because of the trenching and dredging for pipe installation.

- Facility replanning/redesign costs may be incurred if the facility is far enough along in the facility planning and development process. This cost would likely be minimal to negligible for most of the alterations discussed above, but could be much higher for switching a facility to a recirculating cooling system.

- Monitoring costs (e.g., to test for contaminated sediments).

As noted earlier, if the intake structure installation involves disturbance of contaminated sediments, the permitting authority may require special construction procedures, including hauling the sediments to an appropriate disposal facility offsite. This may increase the cost of the project by more than two to three times the original cost estimate.

B.V.a Potential Additional Site-Specific Costs

There are some especially site-specific costs associated with the construction of cooling towers and water intake structures that represent potential additional expenditures a facility may incur to get a technology in place and operational. These costs can be considerable in some individual cases and in such cases would need to be added to cost estimates. The items described below were not included in the National cost estimates presented in this document. General ranges for these costs are provided in the descriptions below.[13]

These potential site-specific costs that need to be added where applicable are:

- Pilot studies,
- Geotechnical allowance,
- Land acquisition,
- Interest,
- Legal, fiscal, and administrative expenses, and
- Sales tax.

The following subsections describe each of these indirect cost elements in more detail.

Pilot Studies

Site-specific pilot tests are often required by regulatory agencies to better define design conditions and to ensure protection of public health by the proposed technology. Pilot tests can be run to determine appropriate loading rates, chemical feed rates or other process parameters, waste handling requirements, and whether a facility is likely to meet requirements for noise and air drift control (for cooling towers) and other emissions limits.

Requirements of predesign testing can be satisfied through several alternatives. Among these are full- or small-scale pilot studies, bench tests, and desktop feasibility studies. In addition, participating in cooperative studies between suppliers, associations, and users can sometimes reduce costs for such pre-design requirements.

The general costs for each type of study range from an inexpensive, small-scale pilot study to full-scale pilot studies that are warranted by site-specific conditions. Performing a full-scale pilot study with the actual process equipment, as installed on-site, can sometimes reduce equipment costs. Three variables affecting these costs are technology requirements, existing standard protocol requirements, and state requirements. Some states may determine test requirements on a case-by-case basis particularly where stringent fish protection, NPDES, and noise and plume abatement regulations exist.

The diversity of state requirements, along with the many options for pre-design testing, results in poorly defined requirements for pilot or bench scale studies. To determine costs, a strong definition of pilot scale testing requirements is necessary.

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[13]Because these costs are so site-specific, an individual cost estimate would not be appropriate on a National basis. In addition, costs may vary substantially by region. For example, weighted unit cost averages for 689 cities range from 0.653 to 1.352, with a 30-city average index of 1.0 (R.S. Means, 1997a). City indices are available on the Internet on various sites and provide a tool for adjusting estimated costs to be more reflective of potential costs in specific geographic locations.

Table A-31 shows estimated hours and cost for a pilot test and is the result of a combination of available information, contacts with vendors for verification, and review of references.

Table A-31. Potential Pilot Test Costs for Screens and Cooling Towers (1999 Dollars)

Element	Hours	Cost	Assumptions
P.E./P.M.	12		1. A 2-week pilot study test is sufficient. 2. P.M./P.E. will arrange and coordinate test. 3. Selection of technology performed in the process design phase of the project. 4. A brief report will be prepared describing test, results and recommendations. 5. Other costs include power costs, chemical costs, sludge disposal, and one effluent sample per day for TSS, turbidity, and three volatile organic constituents.
Junior Engineer	40		
Word Processor	16		
Pilot System Rental		$10,000	
Other costs		$4,000	

Geotechnical Allowance

Cost estimates should include a geotechnical allowance for any unique subsurface conditions that require special construction techniques, such as piles or high ground water table dewatering. These costs are very site-specific.

Land Acquisition

Cost estimates for purchasing land for buildings, facility units, and conveyance should be included, if necessary. The amount of land required should include a 40-foot buffer on each side for emergency vehicle access. Typical costs per acre range from $4,000 to $350,000 for industrial sites and from $150 to $2,200 for rural sites. Average costs are $10,000 per industrial acre and $1,000 per rural acre. (EPA, 1996)

Interest

Cost estimates may need to include interest for the financing of the project. The interest rate depends on the funding source, subsidies, and the general economy, but generally ranges from 3% to 10%. The interest on capital expenses during construction generally ranges between 5% and 10% of capital costs.

Legal, Fiscal and Administrative Expenses

This category includes project management, accounting, and administrative activities related to the project, excluding permitting. The cost can range from 2% to 5% of the equipment, installation, construction, electrical, and standby power cost, with an average of 3%.

Sales Tax

Projects may be exempt from the sales tax, particularly those constructed with public funds. If not, the tax can be as high as 7.25% of the equipment and construction cost, with a National average of 4.75% (R.S. Means, 1997a).

C. REFERENCES

In addition to the references listed below, EPA would like to thank the following individuals for providing valuable information, comments and support: Russel Bellman and Brian Julius, Acting Chief, Gulf Coast Branch NOAA Damage Assessment Center, Silver Spring, MD, of the National Oceanic and Atmospheric Administration; Adnan Alsaffar, Arman Sanver, and John Gantnier, Bechtel Power Corporation, Fredrick, MD; Gary R. Mirsky Vice President, Hamon Cooling Towers, Somerville, NJ; Jim Prillaman, Prillaman Cooling Towers, Richmond, VA; Ken Campbell GEA Power Systems, Denver, CO and David Sanderlin, GEA Power Systems, San Diego, CA; Michael D. Quick, Manager - Marketing / Communications, U.S. Filter - Envirex Products, Waukesha, WI; Trent T. Gathright, Fish Handling Band Screen Specialist, Marketing Manager, Brackett Geiger USA, Inc., Houston, TX; Richard J. Sommers, U.S. Filter Intake Systems, Chalfont,

PA; Ken McKay, VP Sales/Marketing, USF Intake Products; and Larry Sloan, District Representative, Sloan Equipment Sales Co.,Inc., Owings Mills, MD.

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D. LIST OF COST CURVES AND EQUATIONS

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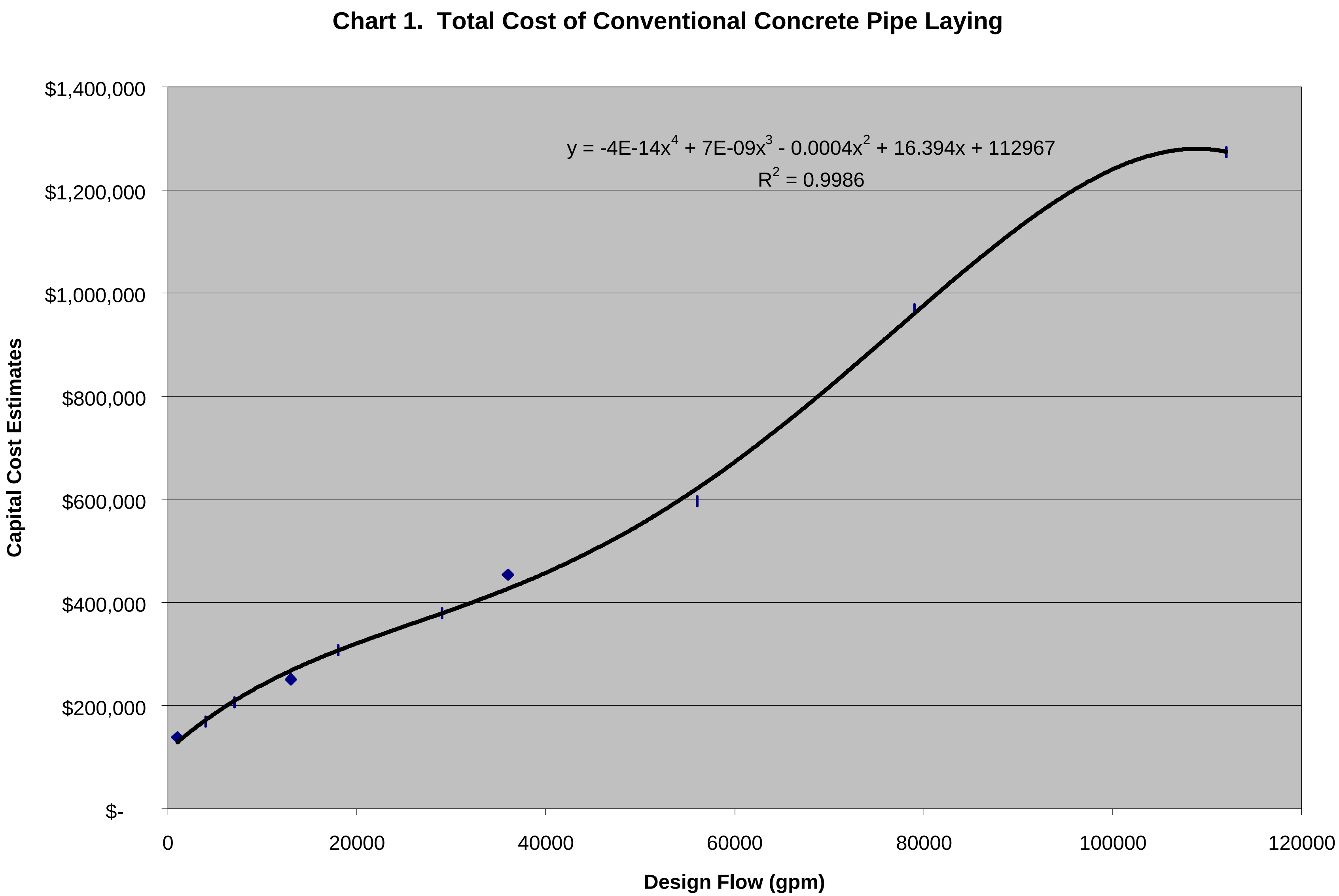


Chart 1. Total Cost of Conventional Concrete Pipe Laying
y = -4E-14x4 + 7E-09x3 - 0.0004x2 + 16.394x + 112967
R2 = 0.9986
Capital Cost Estimates
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$-
0
20000
40000
60000
80000
100000
120000
Design Flow (gpm)

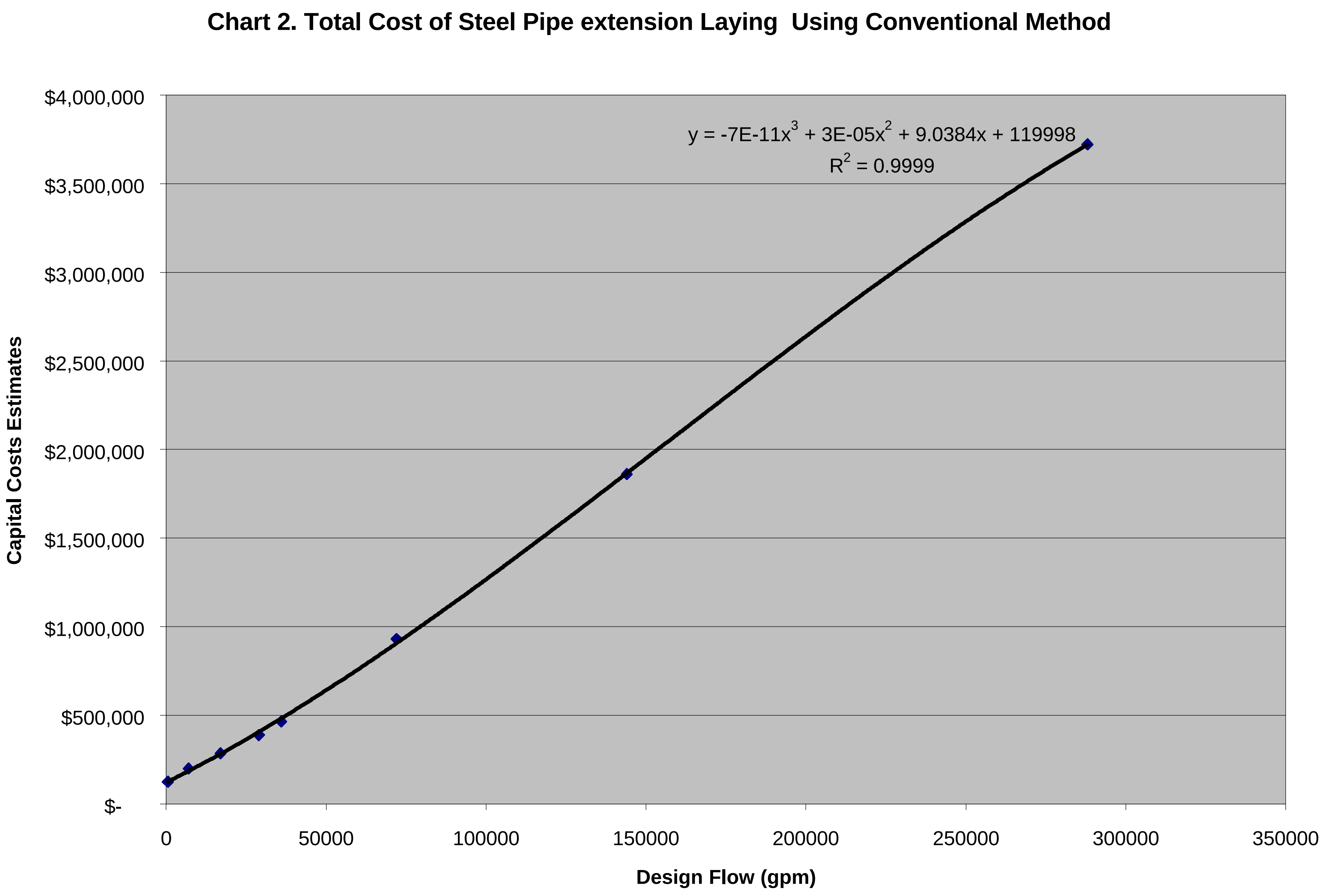


Chart 2. Total Cost of Steel Pipe extension Laying Using Conventional Method
y = -7E-11x3 + 3E-05x2 + 9.0384x + 119998
R2 = 0.9999
$4,000,000
$3,500,000
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$-
Capital Costs Estimates
0
50000
100000
150000
200000
250000
300000
350000
Design Flow (gpm)

Chart 3. Cost of Bottom-pull Concrete Pipe Laying

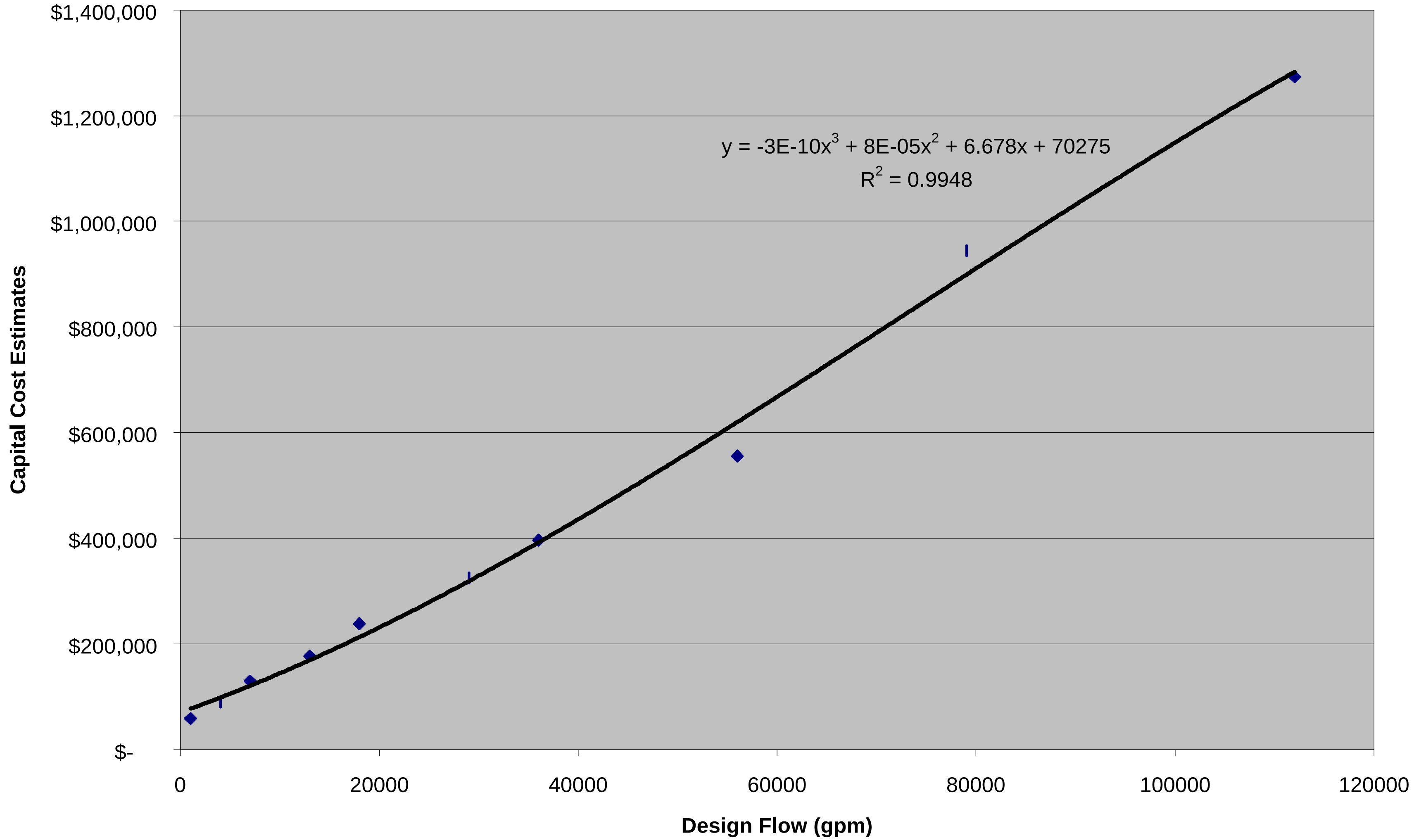


Chart 4. Total Cost of Steel Pipe Extension Using Bottom-pull Laying Method

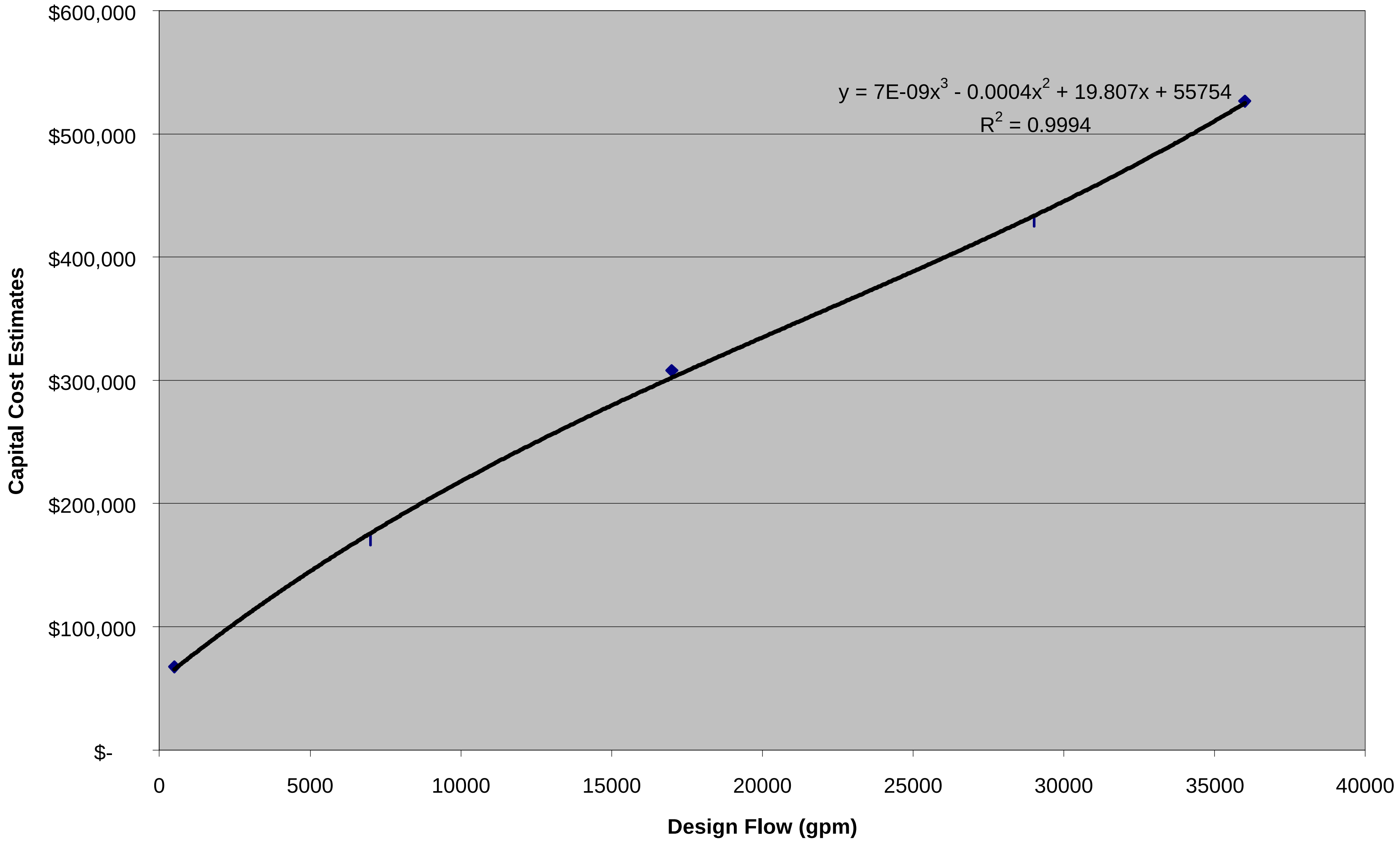


Chart 5. Capital Cost for Extending Intake Pipe 125 Meters Using Micro Tunneling Techniques - Steel Pipe

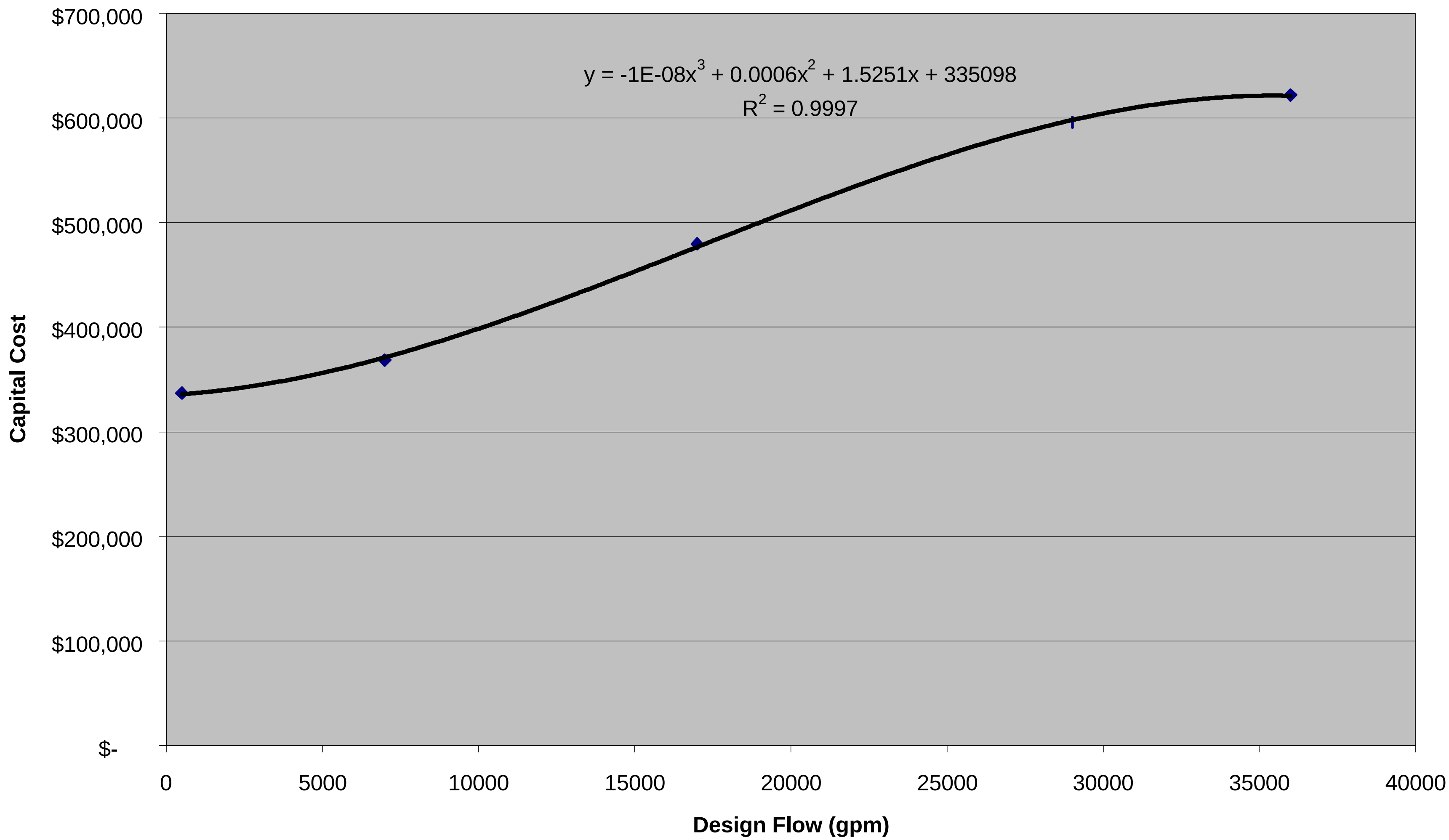


Chart 6. Microtunelling Technique
Capital Cost for 125 meter pipe extension - concrete pipe

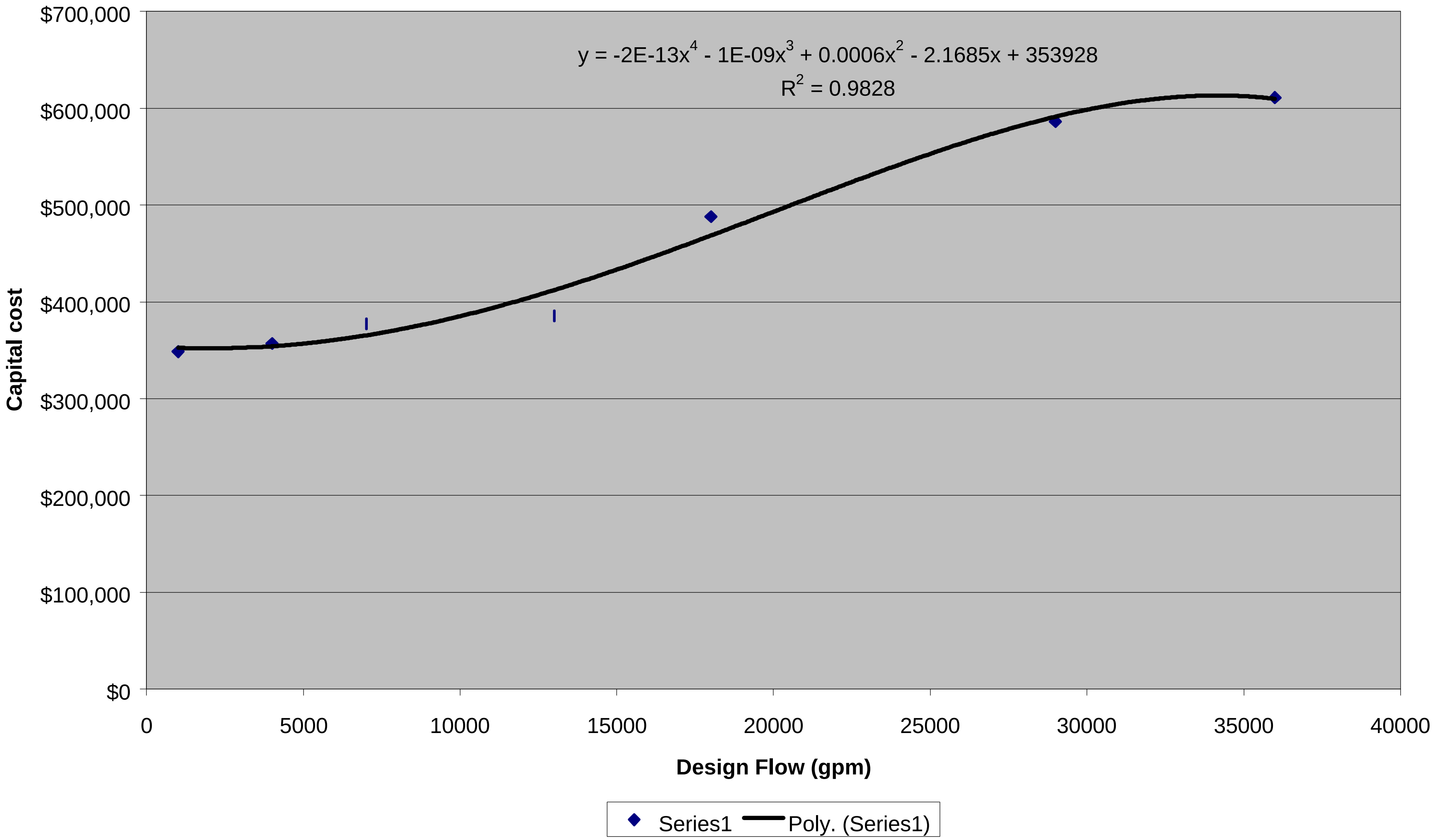


Chart 7. Canal Dredging and Widening Cost

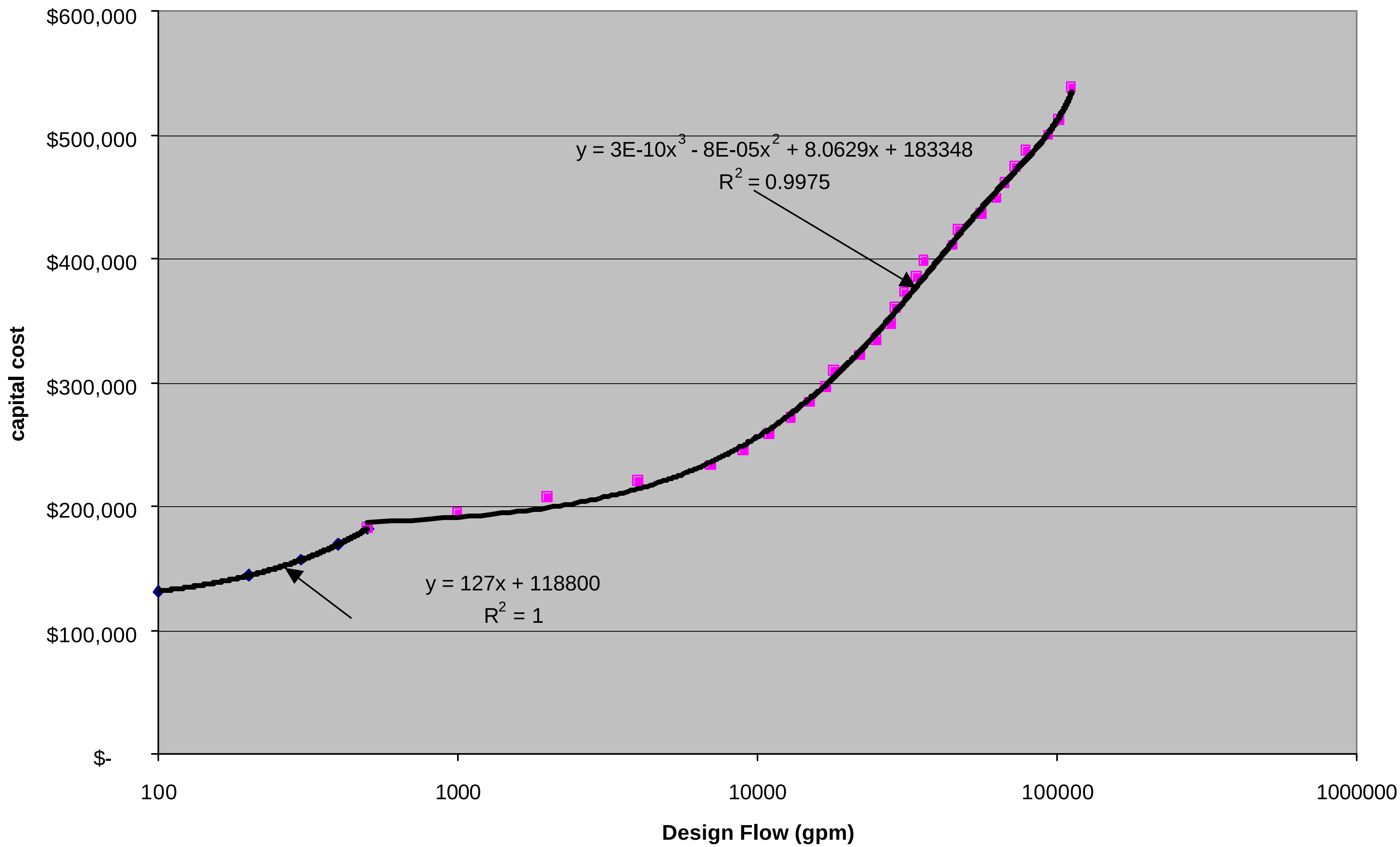


Chart 8. Capital Costs of Basic Cooling Towers with Various Building Material (Delta 10 Degrees)

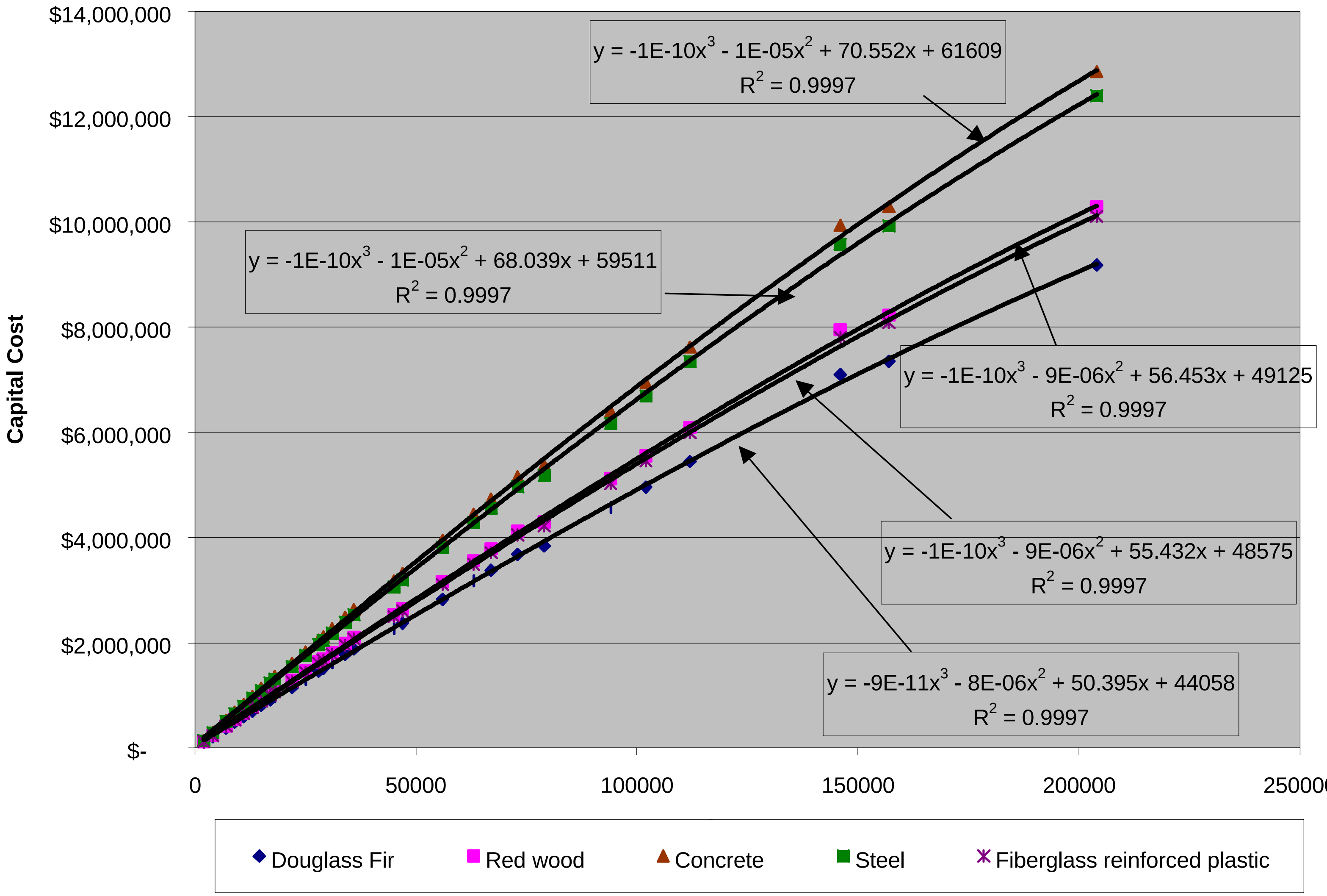


Chart 9. Douglas Fir Cooling Tower Capital Costs with Various Features (Delta 10 Degrees)

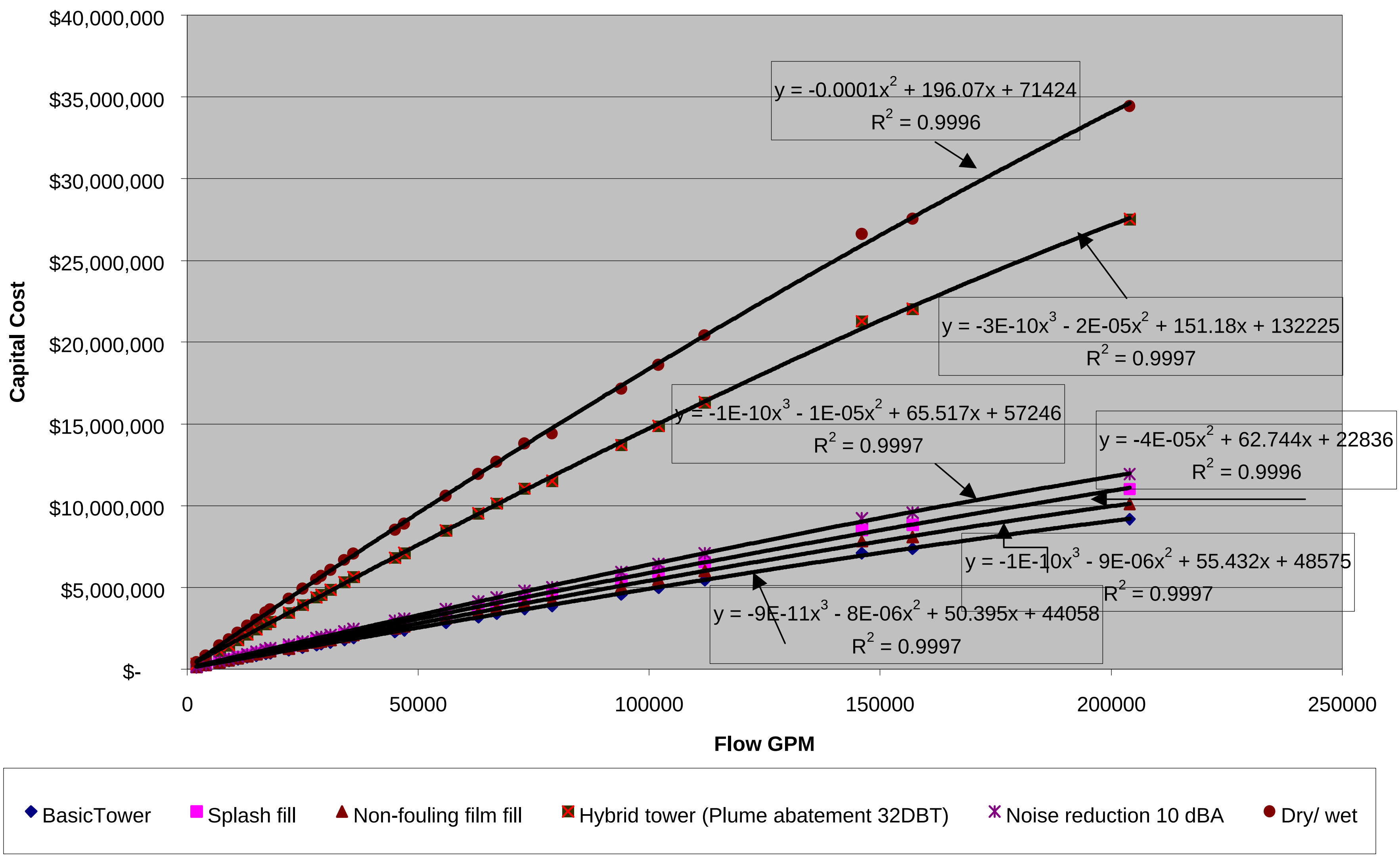


Chart 10. Red Wood Cooling Tower Capital Costs with Various Features (Delta 10 Degrees)

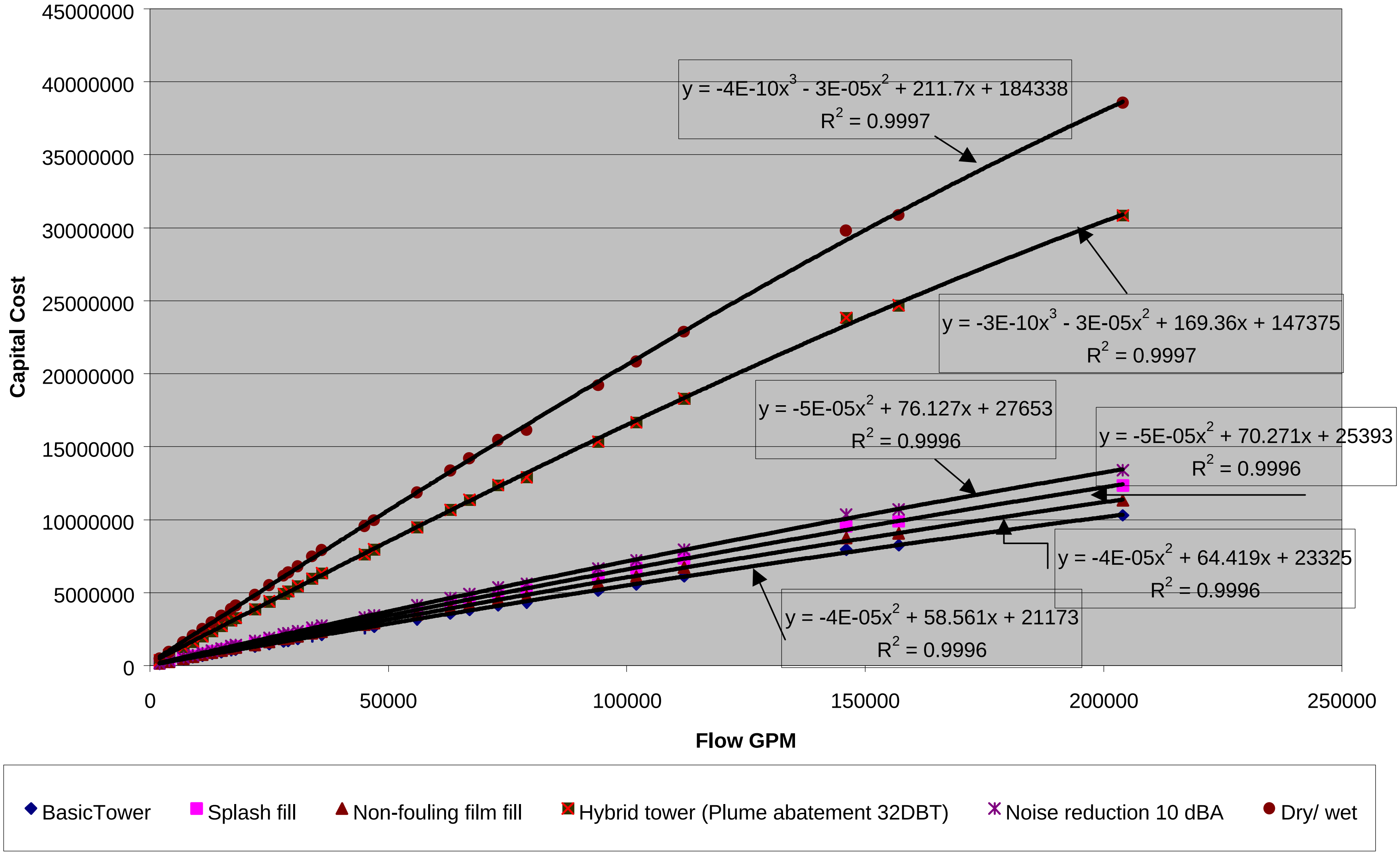


Chart 11. Concrete Cooling Tower Capital Costs with Various Features (Delta 10 Degrees)

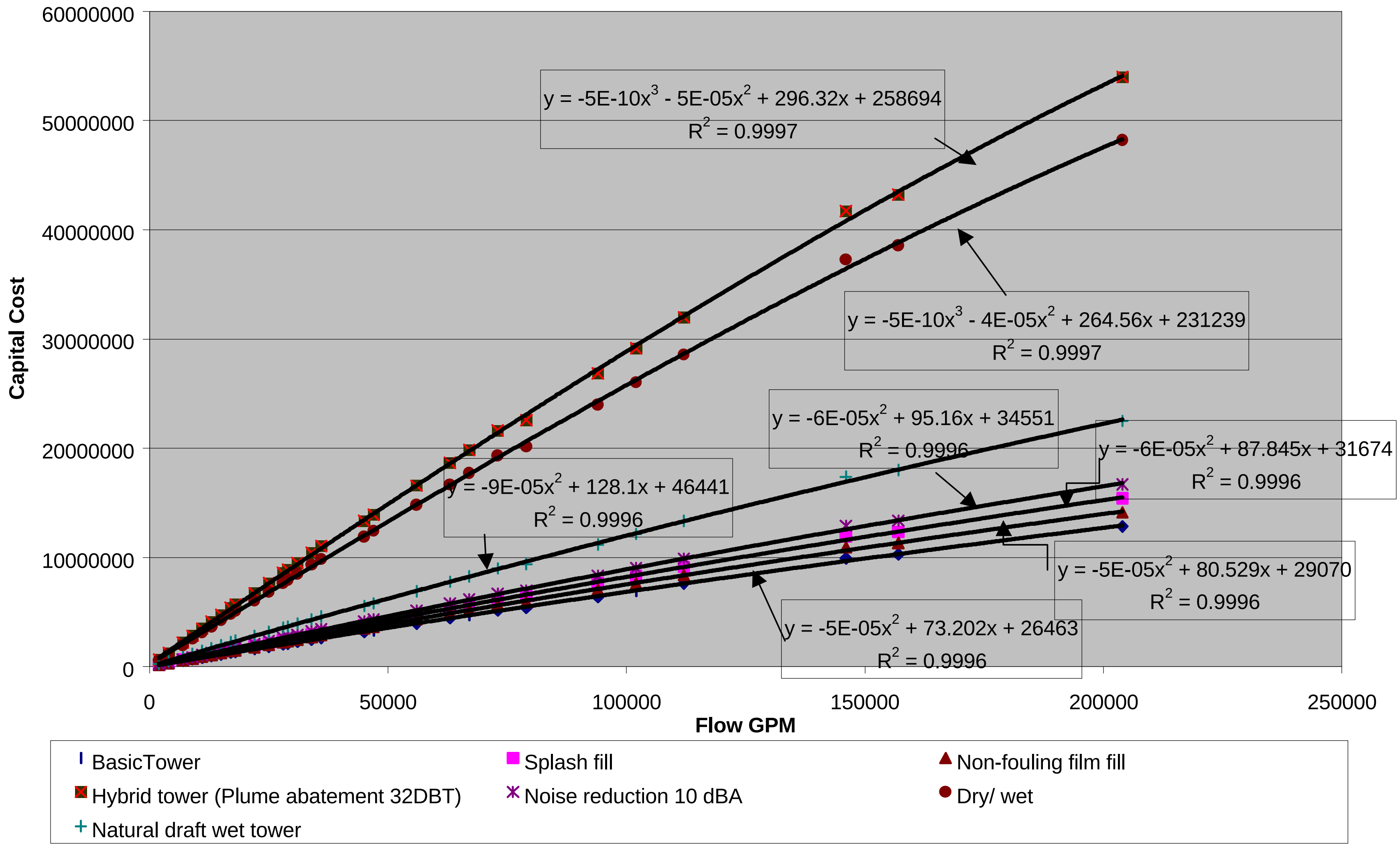


Chart 12. Steel Cooling Tower Capital Costs with Various Features (Delta 10 Degrees)

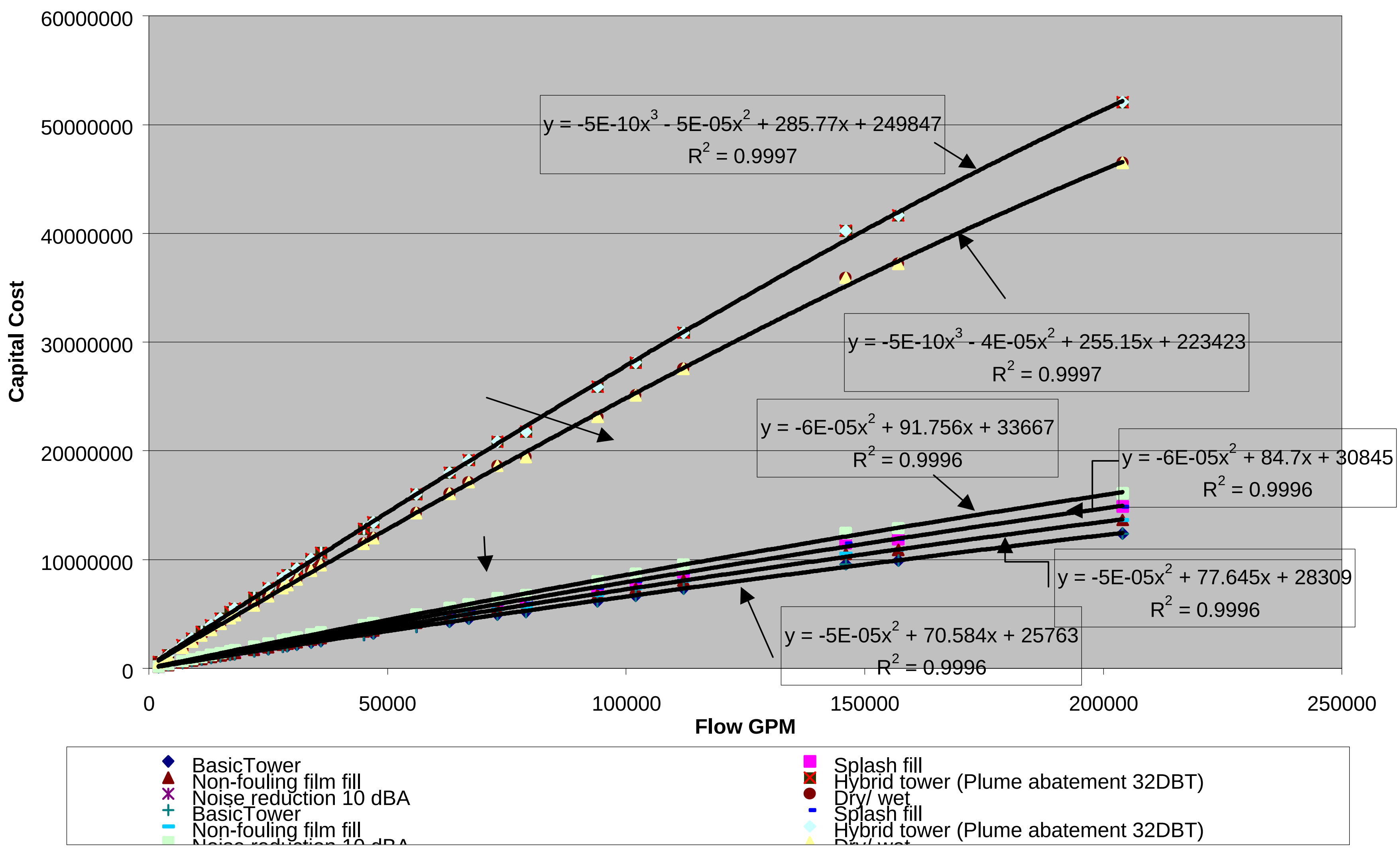
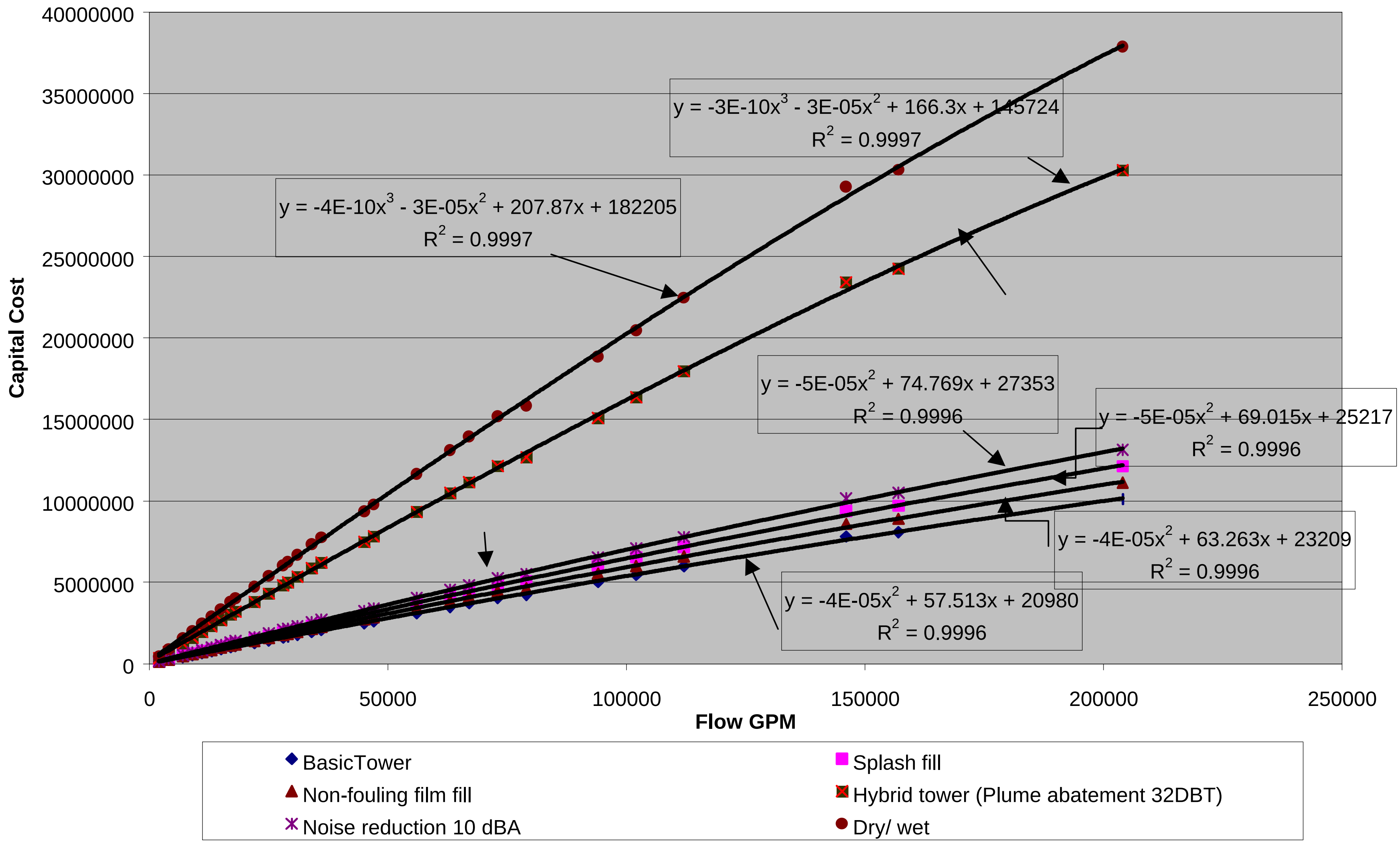


Chart 13. Fiberglass Cooling Tower Capital Costs with Various Features (Delta 10 Degrees)



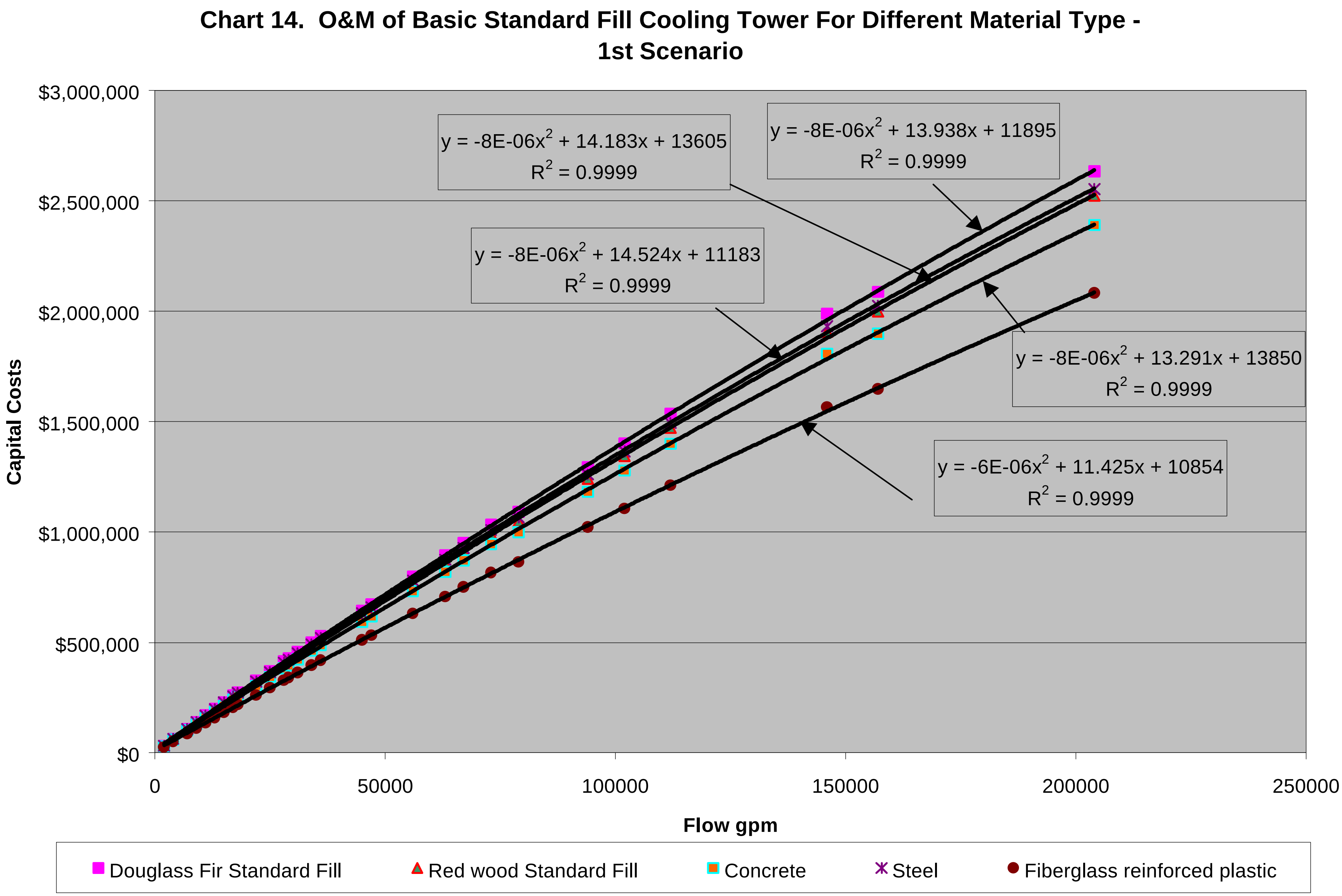


Chart 14. O&M of Basic Standard Fill Cooling Tower For Different Material Type - 1st Scenario
y = -8E-06x2 + 14.183x + 13605
R2 = 0.9999
y = -8E-06x2 + 13.938x + 11895
R2 = 0.9999
y = -8E-06x2 + 14.524x + 11183
R2 = 0.9999
y = -8E-06x2 + 13.291x + 13850
R2 = 0.9999
y = -6E-06x2 + 11.425x + 10854
R2 = 0.9999
Capital Costs
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
0
50000
100000
150000
200000
250000
Flow gpm
Douglass Fir Standard Fill
Red wood Standard Fill
Concrete
Steel
Fiberglass reinforced plastic

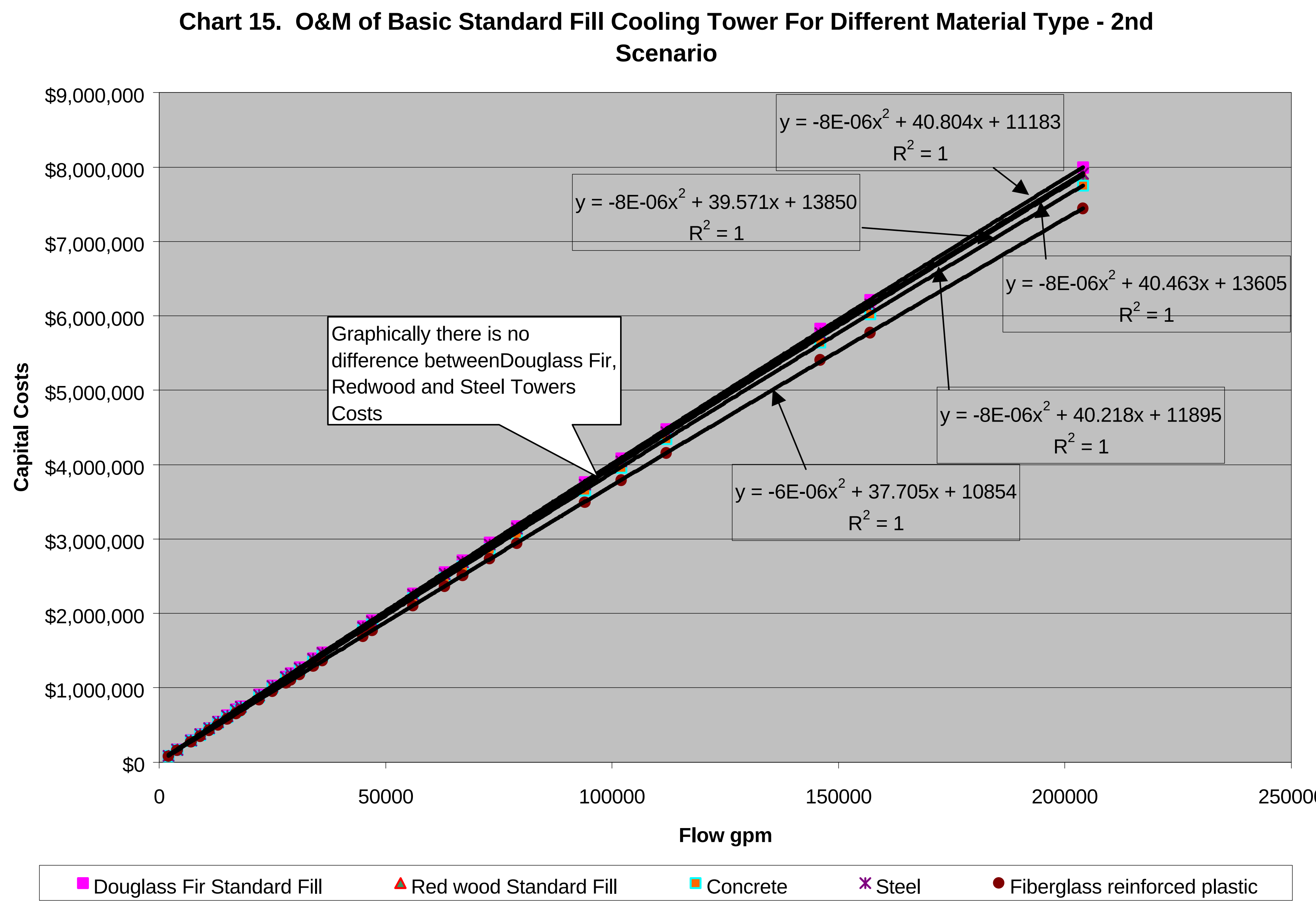
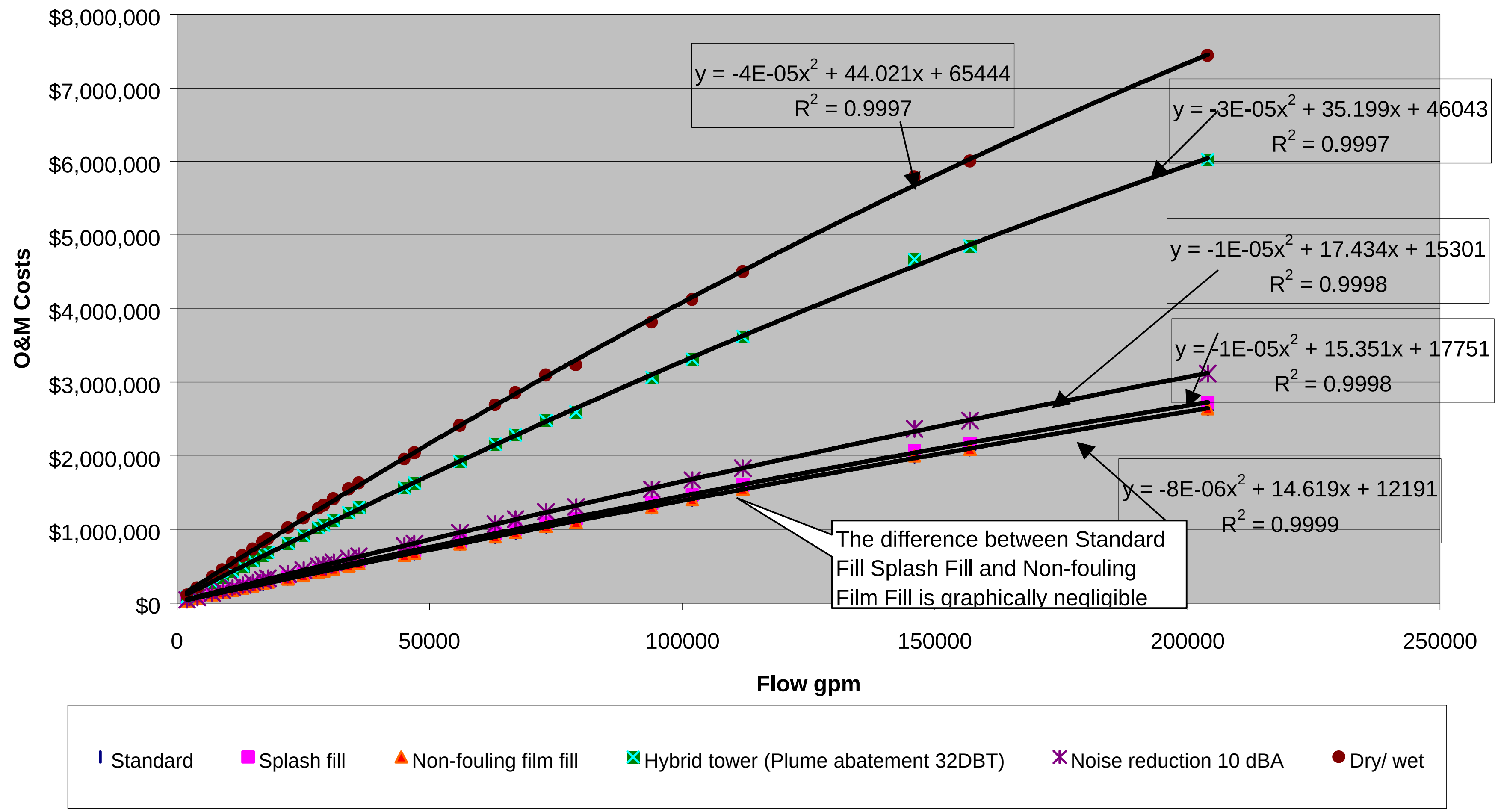


Chart 15. O&M of Basic Standard Fill Cooling Tower For Different Material Type - 2nd Scenario
$9,000,000
$8,000,000
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
Capital Costs
0
50000
100000
150000
200000
250000
Flow gpm
y = -8E-06x2 + 40.804x + 11183
R2 = 1
y = -8E-06x2 + 39.571x + 13850
R2 = 1
y = -8E-06x2 + 40.463x + 13605
R2 = 1
y = -8E-06x2 + 40.218x + 11895
R2 = 1
y = -6E-06x2 + 37.705x + 10854
R2 = 1
Graphically there is no difference betweenDouglass Fir, Redwood and Steel Towers Costs
Douglass Fir Standard Fill
Red wood Standard Fill
Concrete
Steel
Fiberglass reinforced plastic

Chart 16. Total O&M Douglas Fir Tower Annual Cost - 1st Scenario



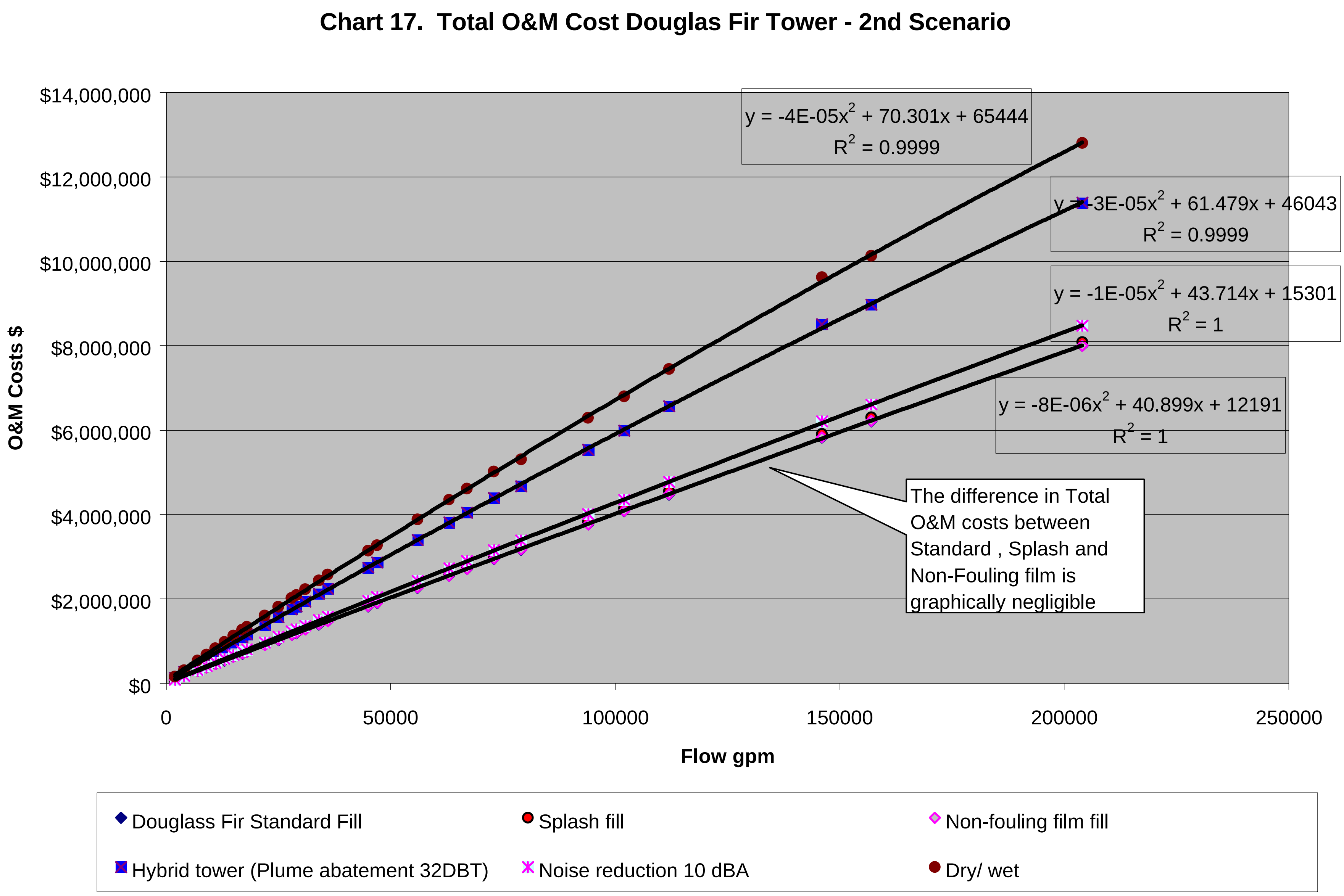
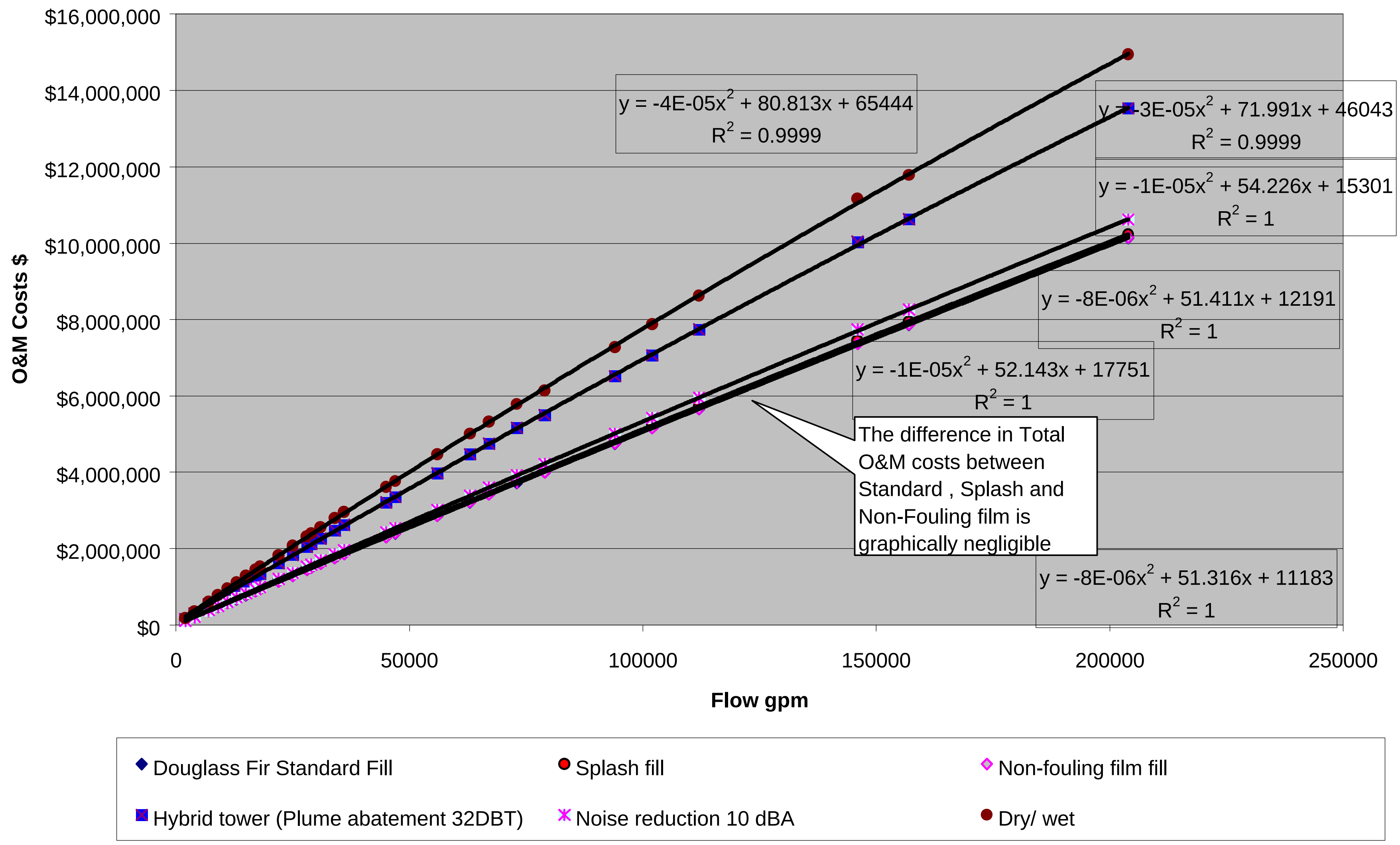


Chart 17. Total O&M Cost Douglas Fir Tower - 2nd Scenario
y = -4E-05x2 + 70.301x + 65444
R2 = 0.9999
y = -3E-05x2 + 61.479x + 46043
R2 = 0.9999
y = -1E-05x2 + 43.714x + 15301
R2 = 1
y = -8E-06x2 + 40.899x + 12191
R2 = 1
The difference in Total O&M costs between Standard , Splash and Non-Fouling film is graphically negligible
O&M Costs $
$14,000,000
$12,000,000
$10,000,000
$8,000,000
$6,000,000
$4,000,000
$2,000,000
$0
0
50000
100000
150000
200000
250000
Flow gpm
Douglass Fir Standard Fill
Splash fill
Non-fouling film fill
Hybrid tower (Plume abatement 32DBT)
Noise reduction 10 dBA
Dry/ wet

Chart 18. Total O&M Cost Douglas Fir Tower - 3rd Scenario



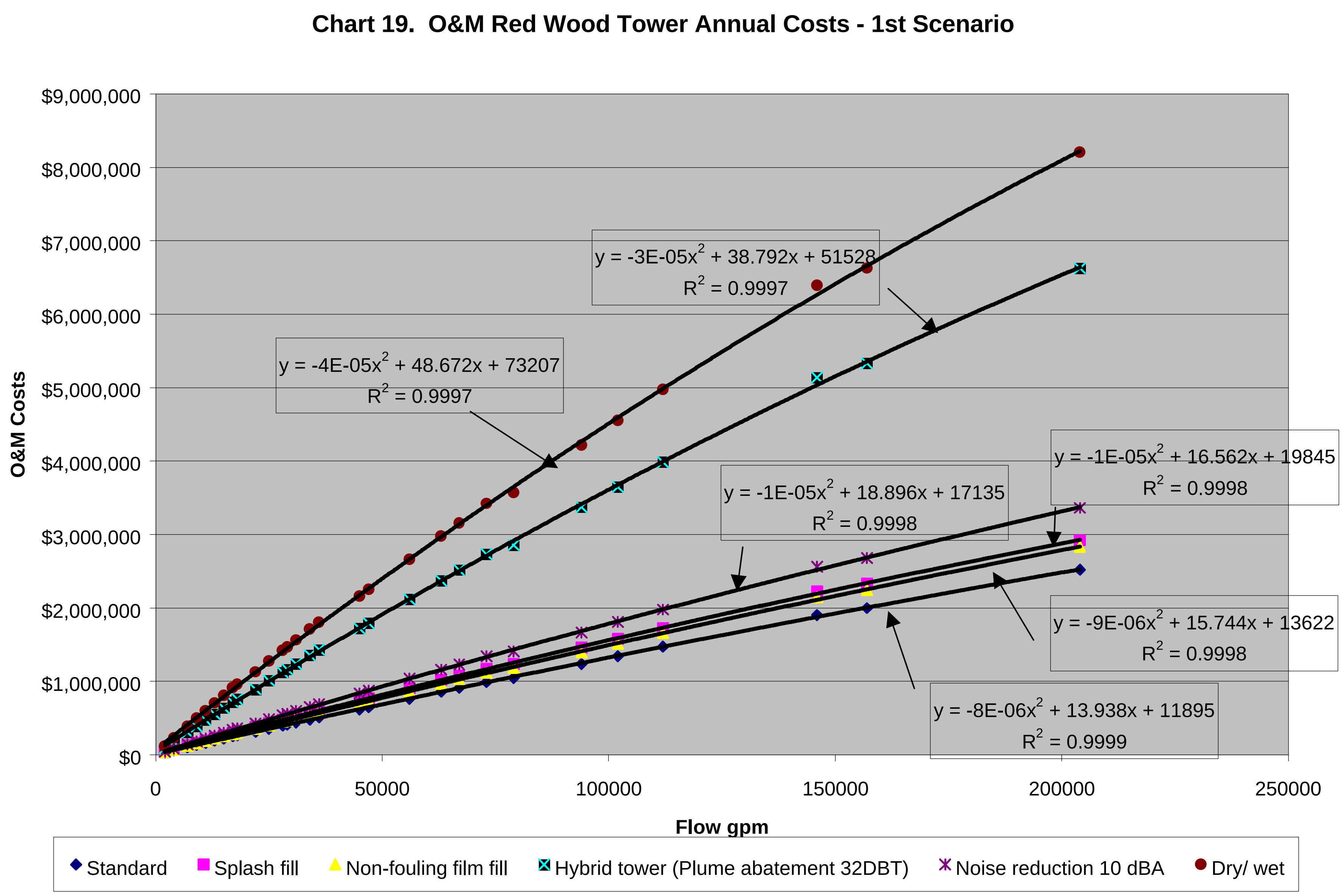


Chart 19. O&M Red Wood Tower Annual Costs - 1st Scenario
O&M Costs
$9,000,000
$8,000,000
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
0
50000
100000
150000
200000
250000
Flow gpm
y = -3E-05x2 + 38.792x + 51528
R2 = 0.9997
y = -4E-05x2 + 48.672x + 73207
R2 = 0.9997
y = -1E-05x2 + 16.562x + 19845
R2 = 0.9998
y = -1E-05x2 + 18.896x + 17135
R2 = 0.9998
y = -9E-06x2 + 15.744x + 13622
R2 = 0.9998
y = -8E-06x2 + 13.938x + 11895
R2 = 0.9999
Standard
Splash fill
Non-fouling film fill
Hybrid tower (Plume abatement 32DBT)
Noise reduction 10 dBA
Dry/ wet

Chart 20. O&M Red Wood Tower Annual Costs - 2nd Scenario

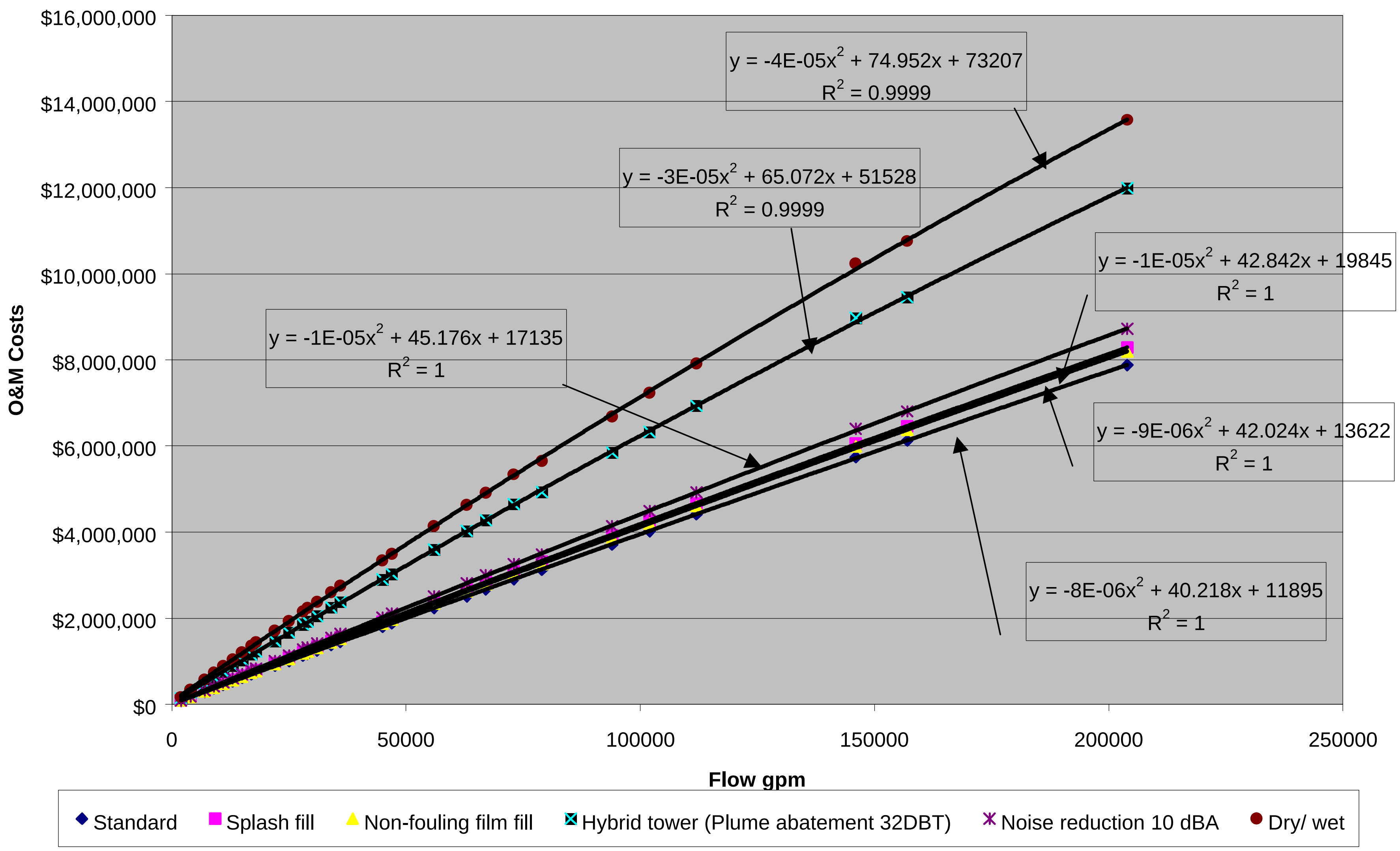


Chart 21. O&M Concrete Tower Annual Costs - 1st Scenario

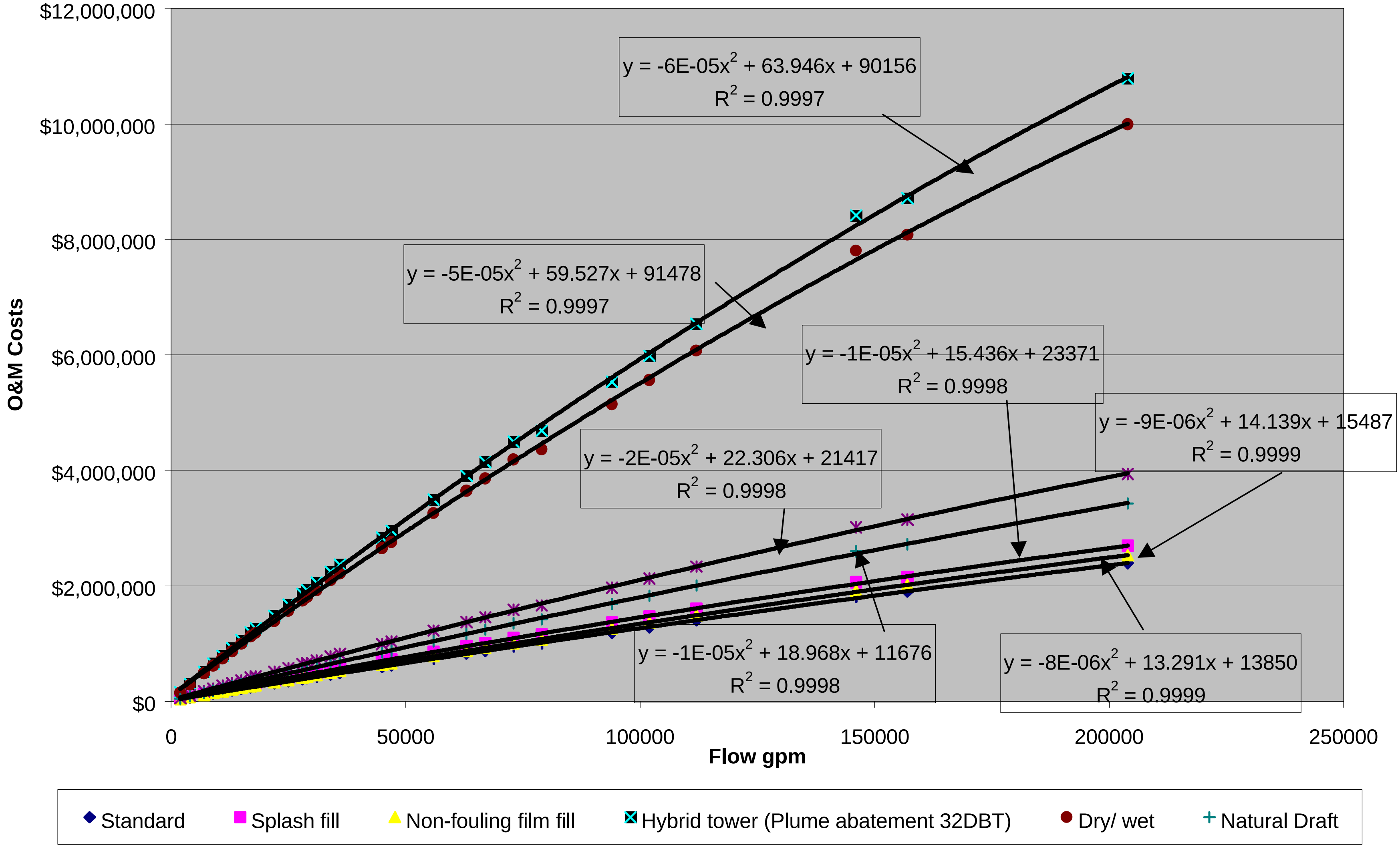


Chart 22. O&M Concrete Tower Annual Costs - 2nd Scenario

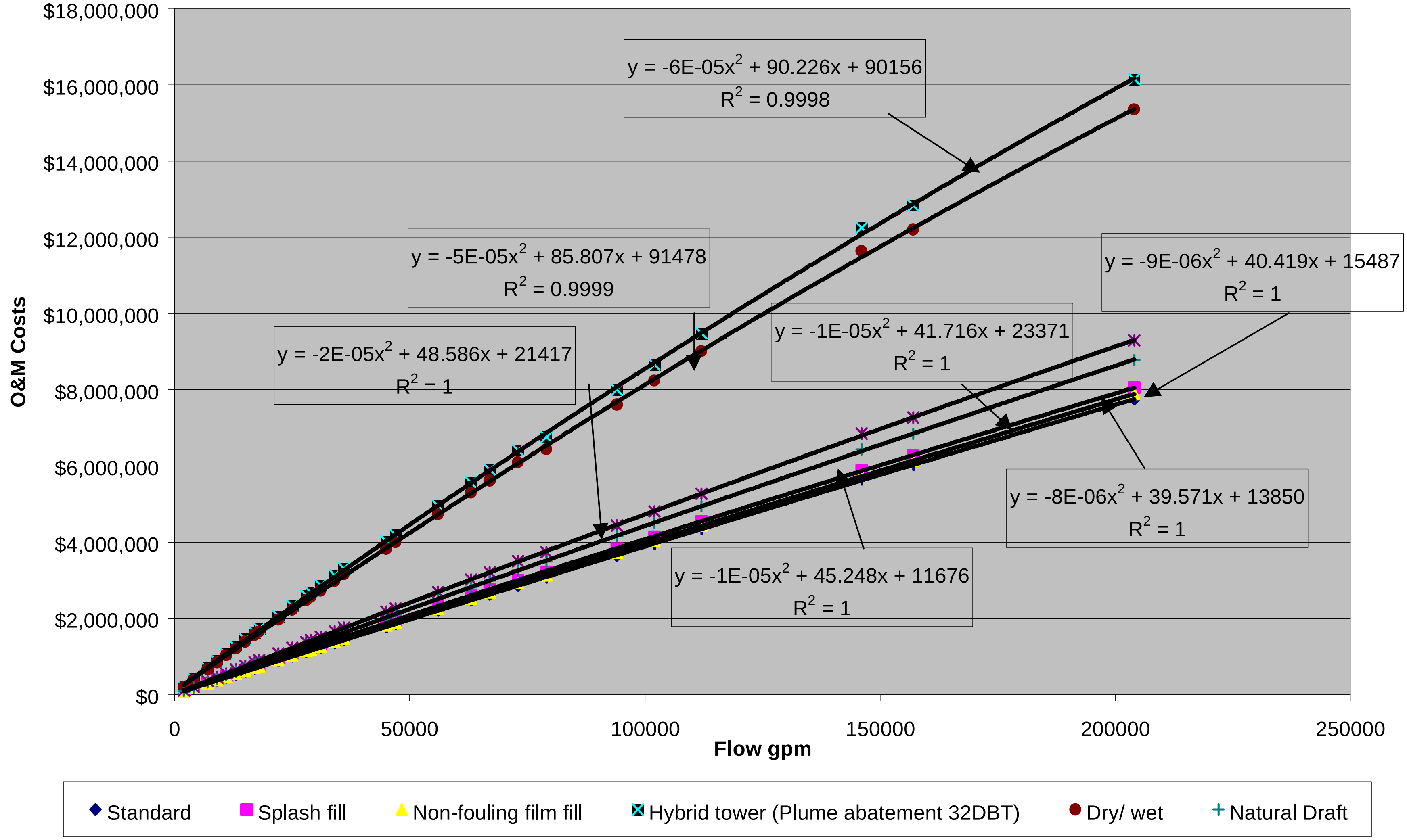
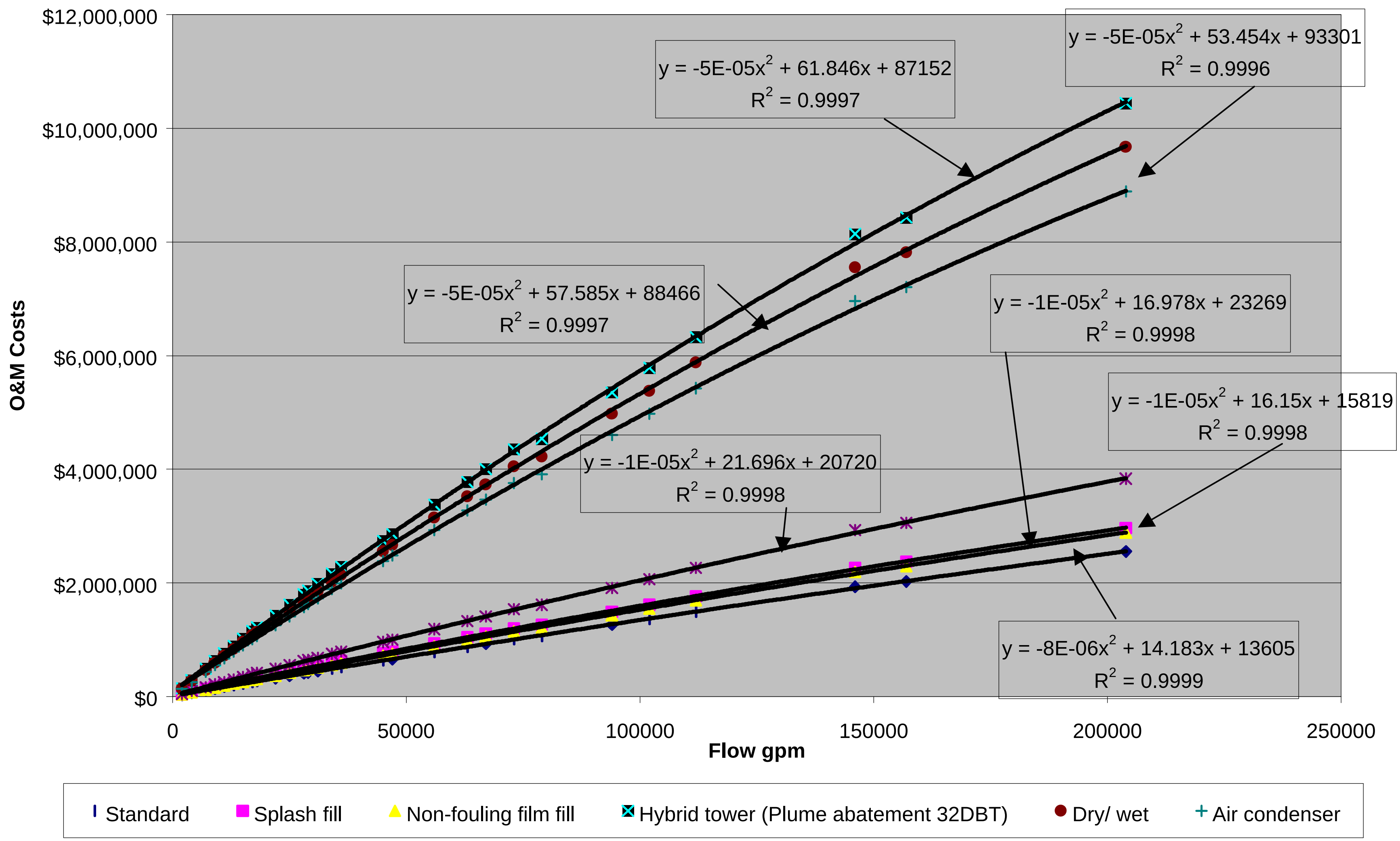


Chart 23. O&M Steel Tower Annual Costs - 1st Scenario



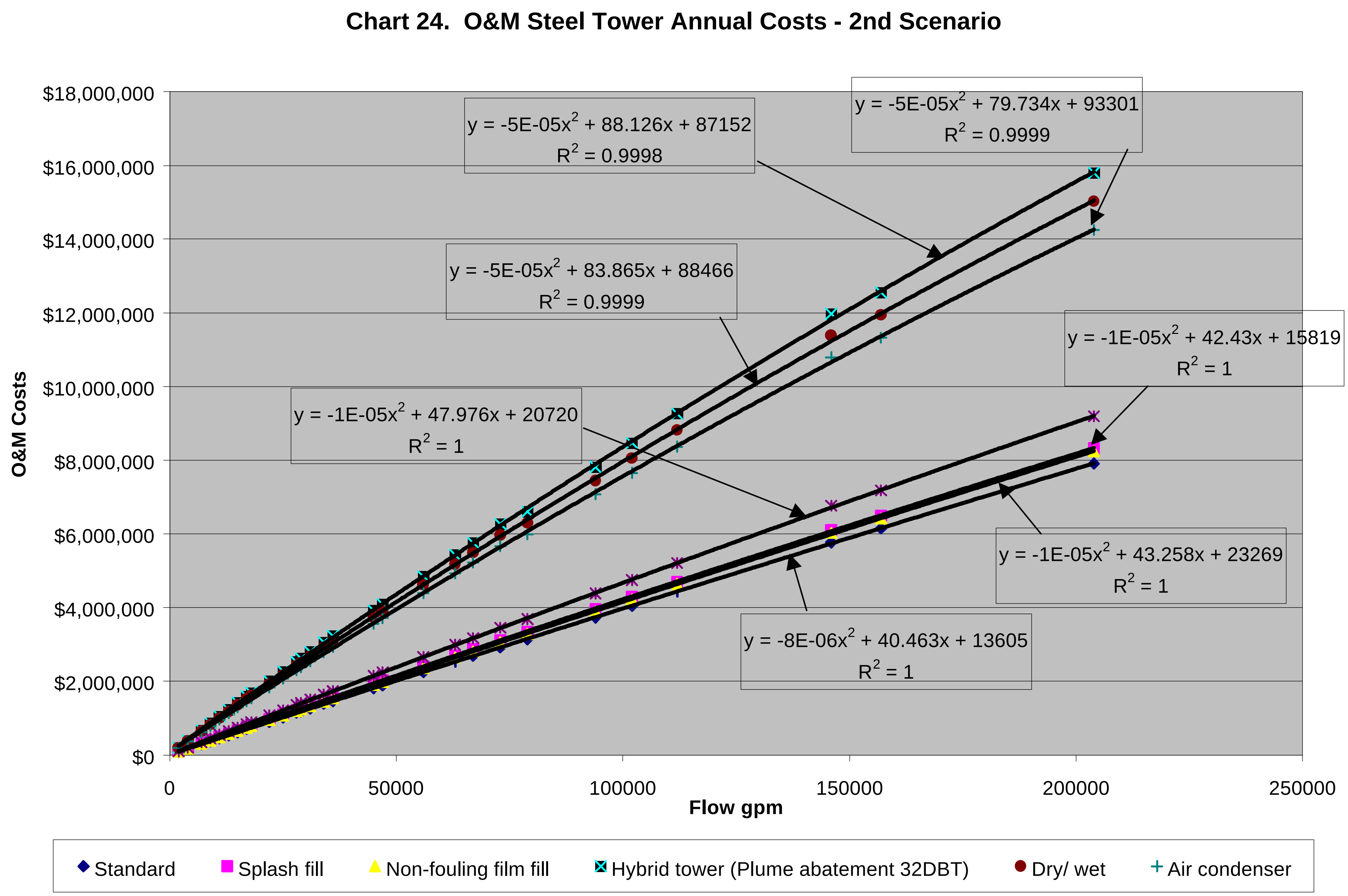


Chart 24. O&M Steel Tower Annual Costs - 2nd Scenario
y = -5E-05x2 + 88.126x + 87152
R2 = 0.9998
y = -5E-05x2 + 79.734x + 93301
R2 = 0.9999
y = -5E-05x2 + 83.865x + 88466
R2 = 0.9999
y = -1E-05x2 + 42.43x + 15819
R2 = 1
y = -1E-05x2 + 47.976x + 20720
R2 = 1
y = -1E-05x2 + 43.258x + 23269
R2 = 1
y = -8E-06x2 + 40.463x + 13605
R2 = 1
O&M Costs
$18,000,000
$16,000,000
$14,000,000
$12,000,000
$10,000,000
$8,000,000
$6,000,000
$4,000,000
$2,000,000
$0
0
50000
100000
150000
200000
250000
Flow gpm
Standard
Splash fill
Non-fouling film fill
Hybrid tower (Plume abatement 32DBT)
Dry/ wet
Air condenser

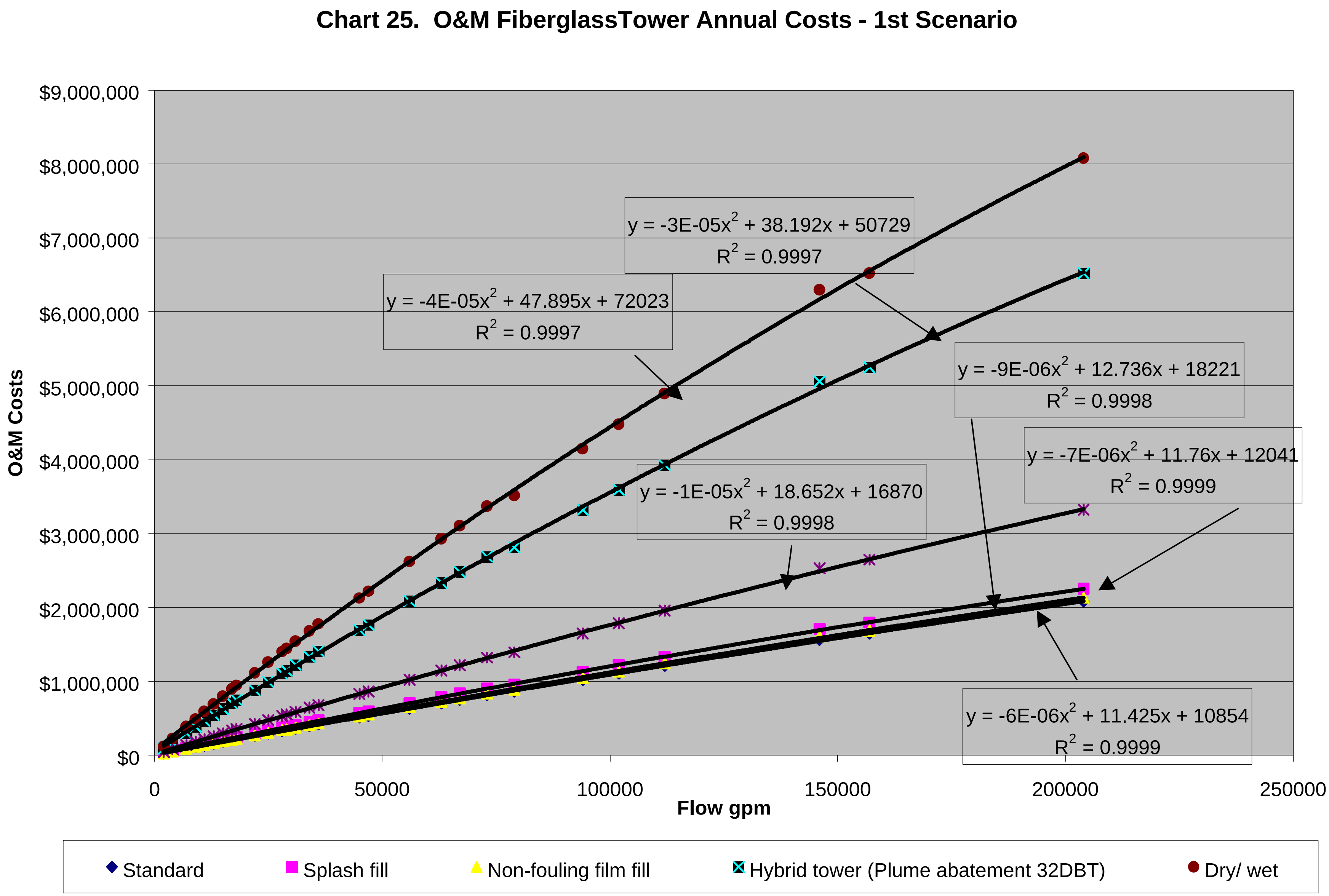


Chart 25. O&M FiberglassTower Annual Costs - 1st Scenario
$9,000,000
$8,000,000
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
O&M Costs
0
50000
100000
150000
200000
250000
Flow gpm
y = -3E-05x2 + 38.192x + 50729
R2 = 0.9997
y = -4E-05x2 + 47.895x + 72023
R2 = 0.9997
y = -9E-06x2 + 12.736x + 18221
R2 = 0.9998
y = -7E-06x2 + 11.76x + 12041
R2 = 0.9999
y = -1E-05x2 + 18.652x + 16870
R2 = 0.9998
y = -6E-06x2 + 11.425x + 10854
R2 = 0.9999
Standard
Splash fill
Non-fouling film fill
Hybrid tower (Plume abatement 32DBT)
Dry/ wet

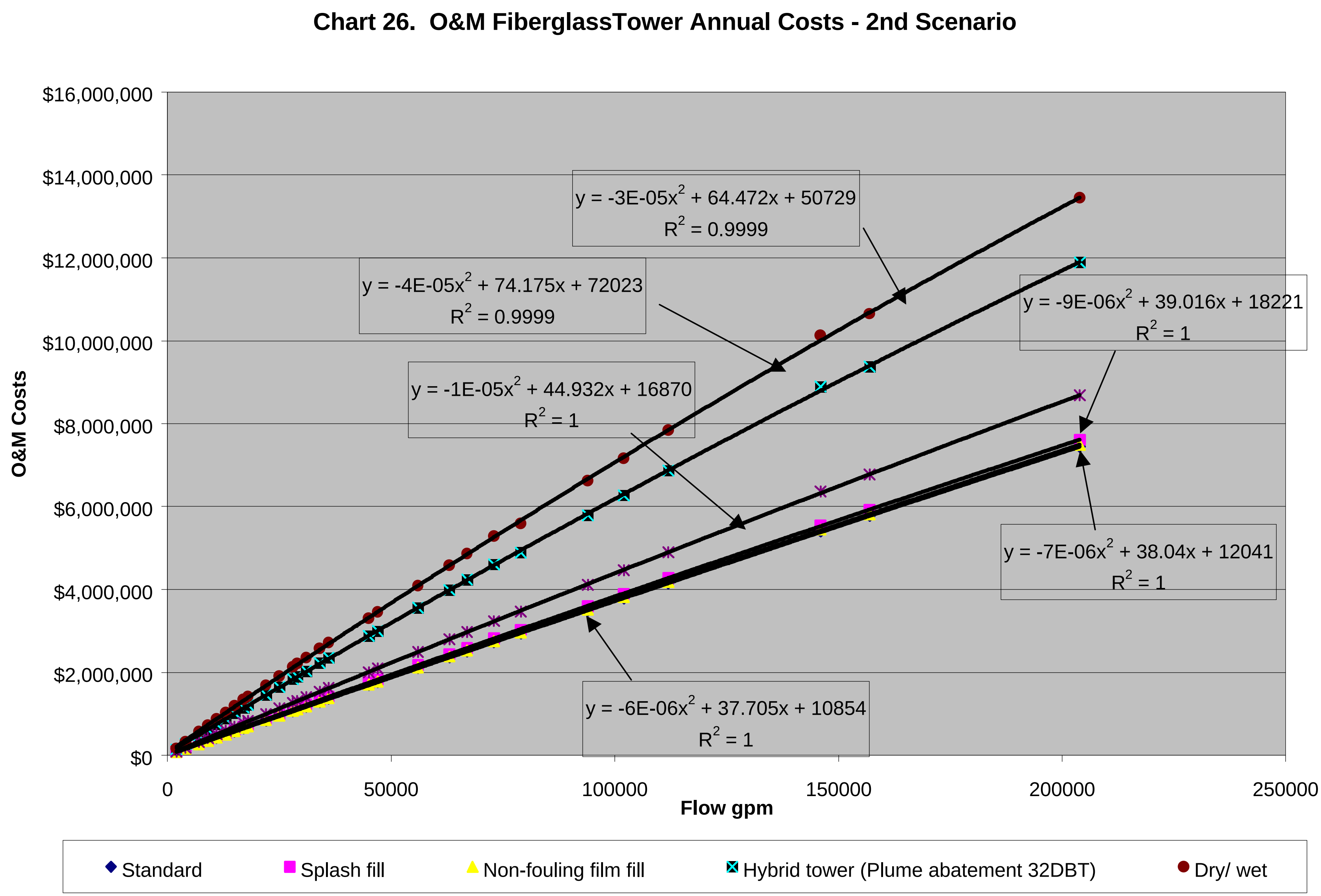


Chart 26. O&M FiberglassTower Annual Costs - 2nd Scenario
$16,000,000
$14,000,000
$12,000,000
$10,000,000
$8,000,000
$6,000,000
$4,000,000
$2,000,000
$0
O&M Costs
0
50000
100000
150000
200000
250000
Flow gpm
y = -3E-05x2 + 64.472x + 50729
R2 = 0.9999
y = -4E-05x2 + 74.175x + 72023
R2 = 0.9999
y = -1E-05x2 + 44.932x + 16870
R2 = 1
y = -9E-06x2 + 39.016x + 18221
R2 = 1
y = -7E-06x2 + 38.04x + 12041
R2 = 1
y = -6E-06x2 + 37.705x + 10854
R2 = 1
Standard
Splash fill
Non-fouling film fill
Hybrid tower (Plume abatement 32DBT)
Dry/ wet

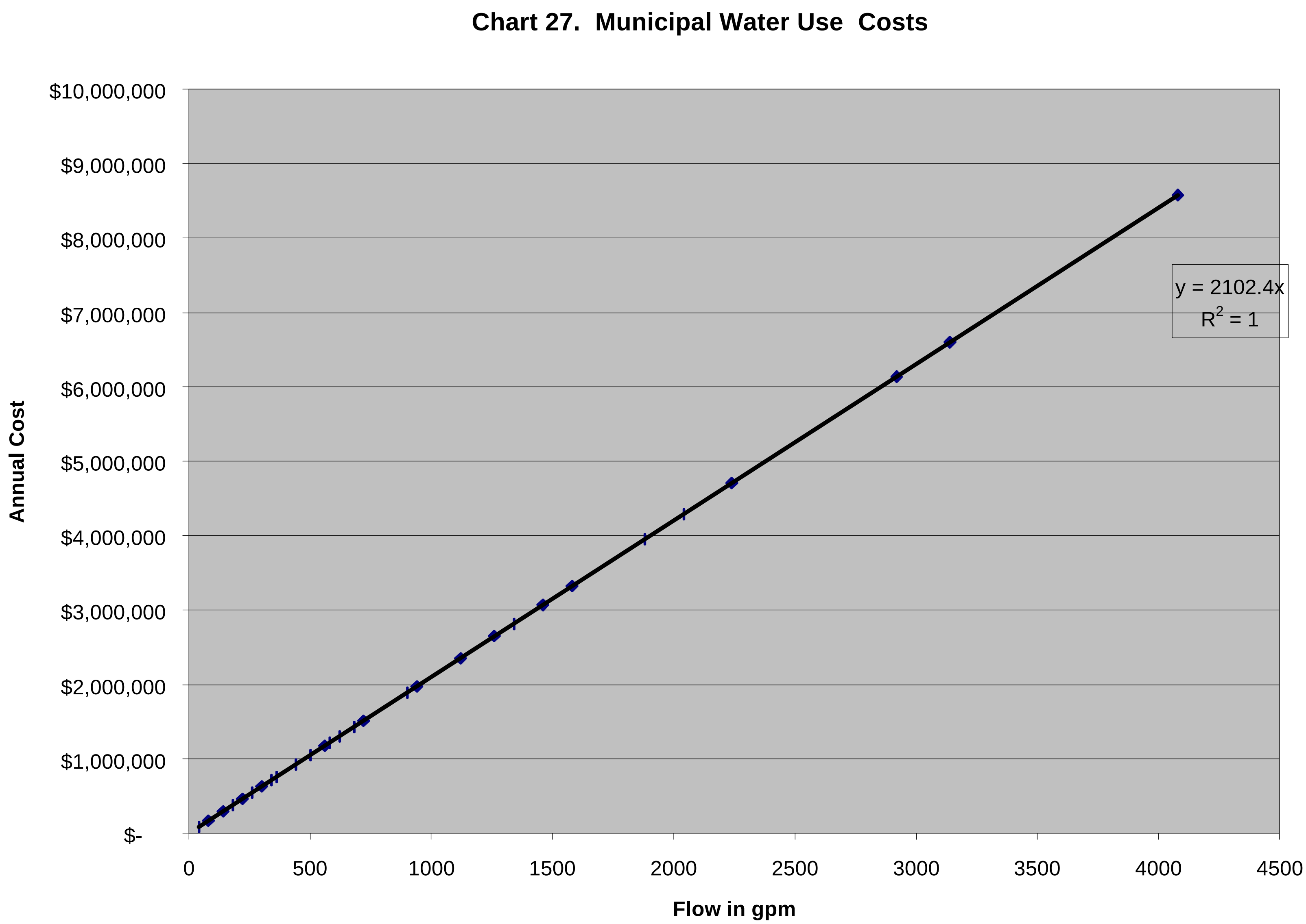


Chart 27. Municipal Water Use Costs
$10,000,000
$9,000,000
$8,000,000
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$-
Annual Cost
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Flow in gpm
y = 2102.4x
R2 = 1

Chart 28. Gray Water Use Costs

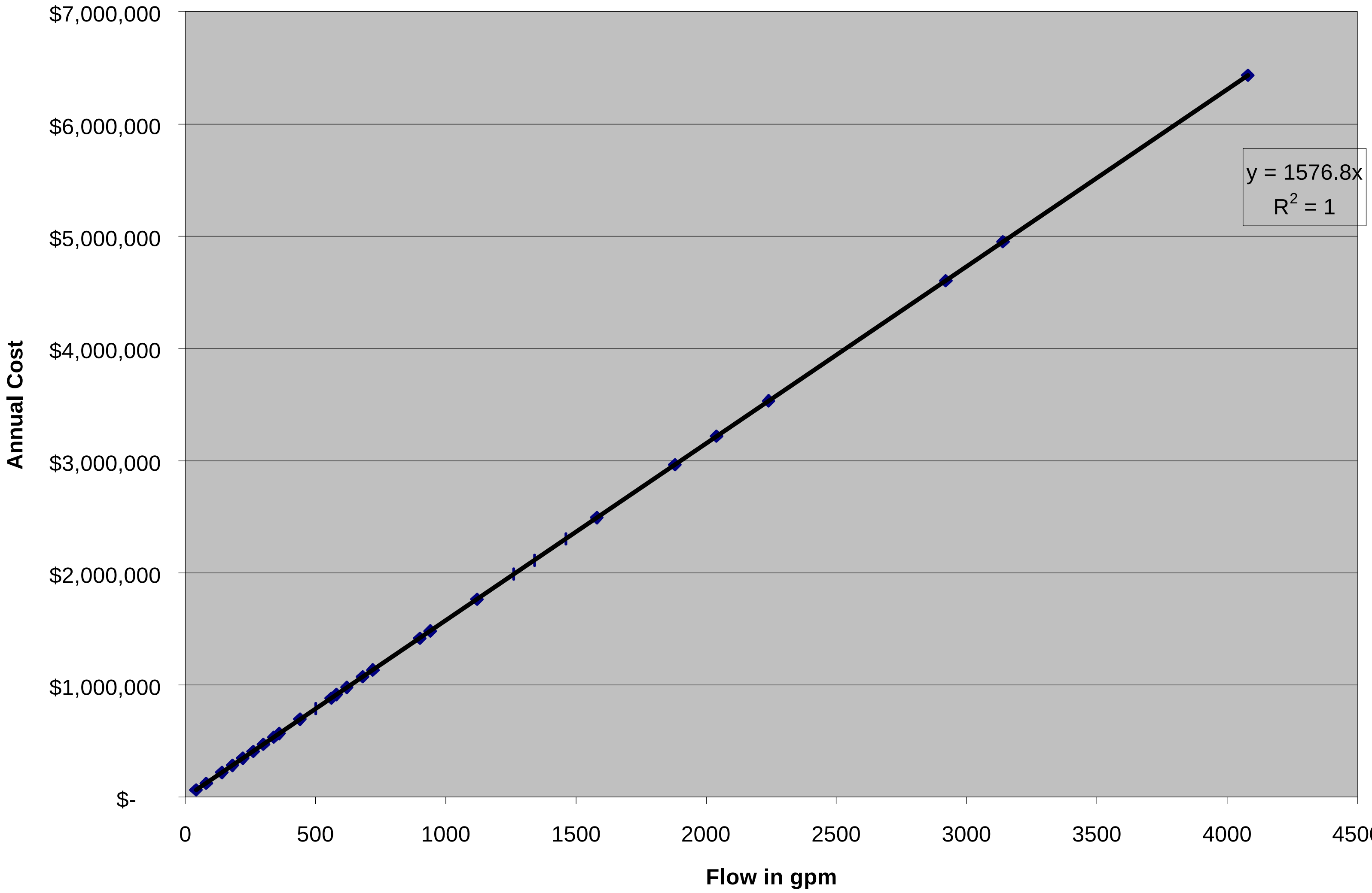


Chart 29. Capital Costs of Passive Screens Based on Well Depth

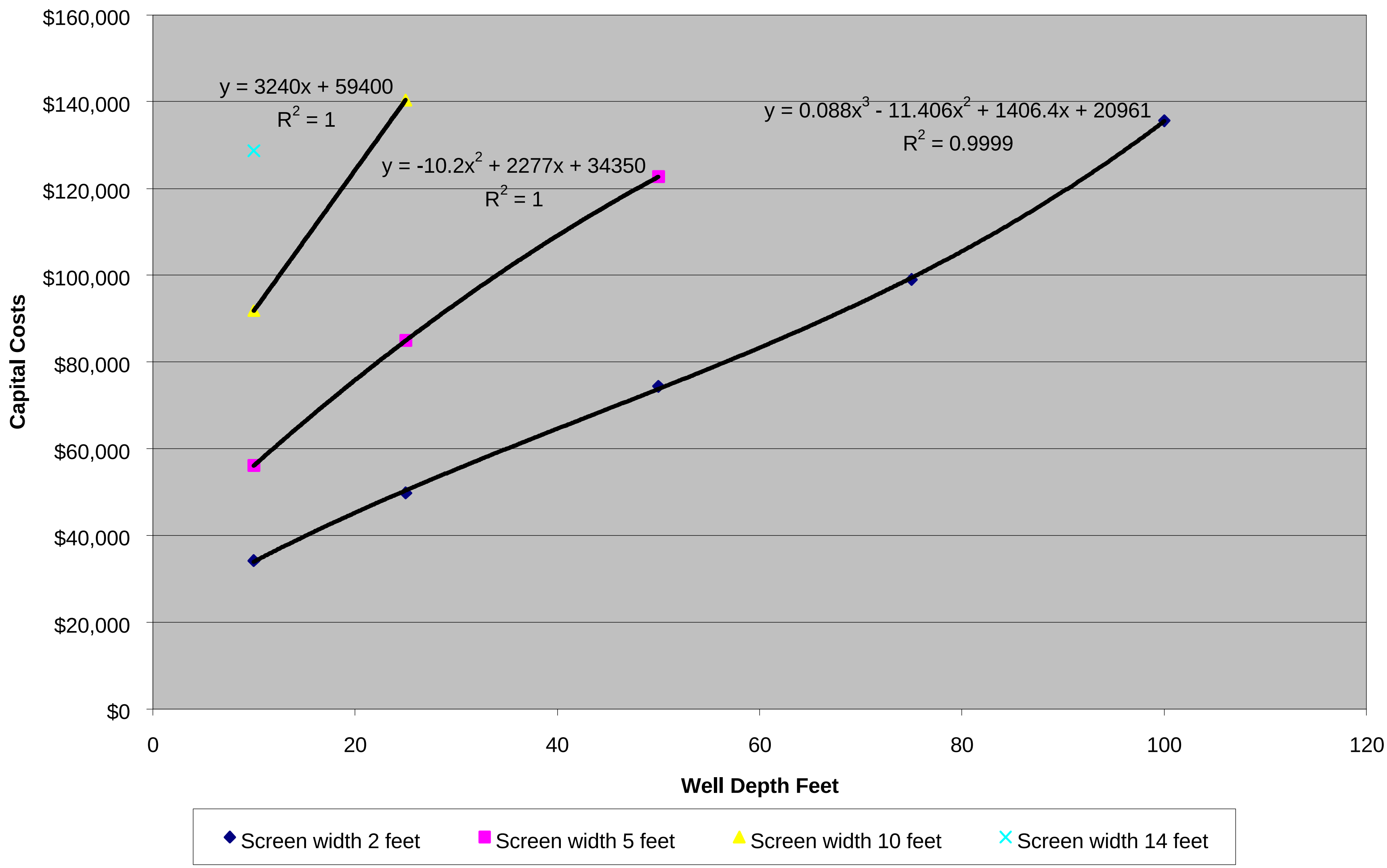


Chart 30. Capital Costs of Passive Screens for a Flow Velocity 0.5 ft/sec

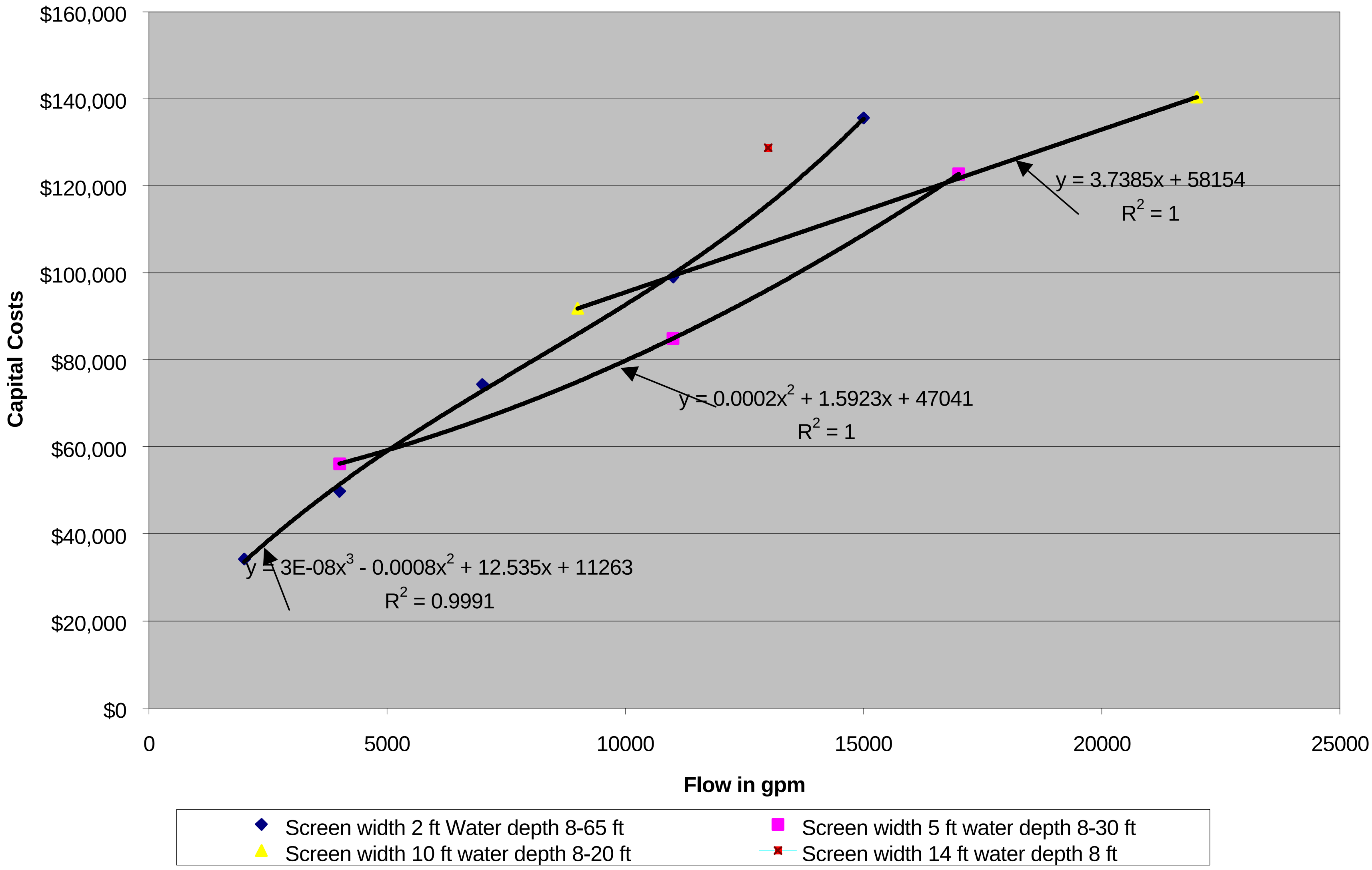


Chart 31. Capital Costs of Passive Screens for a Flow Velocity 1 ft/sec

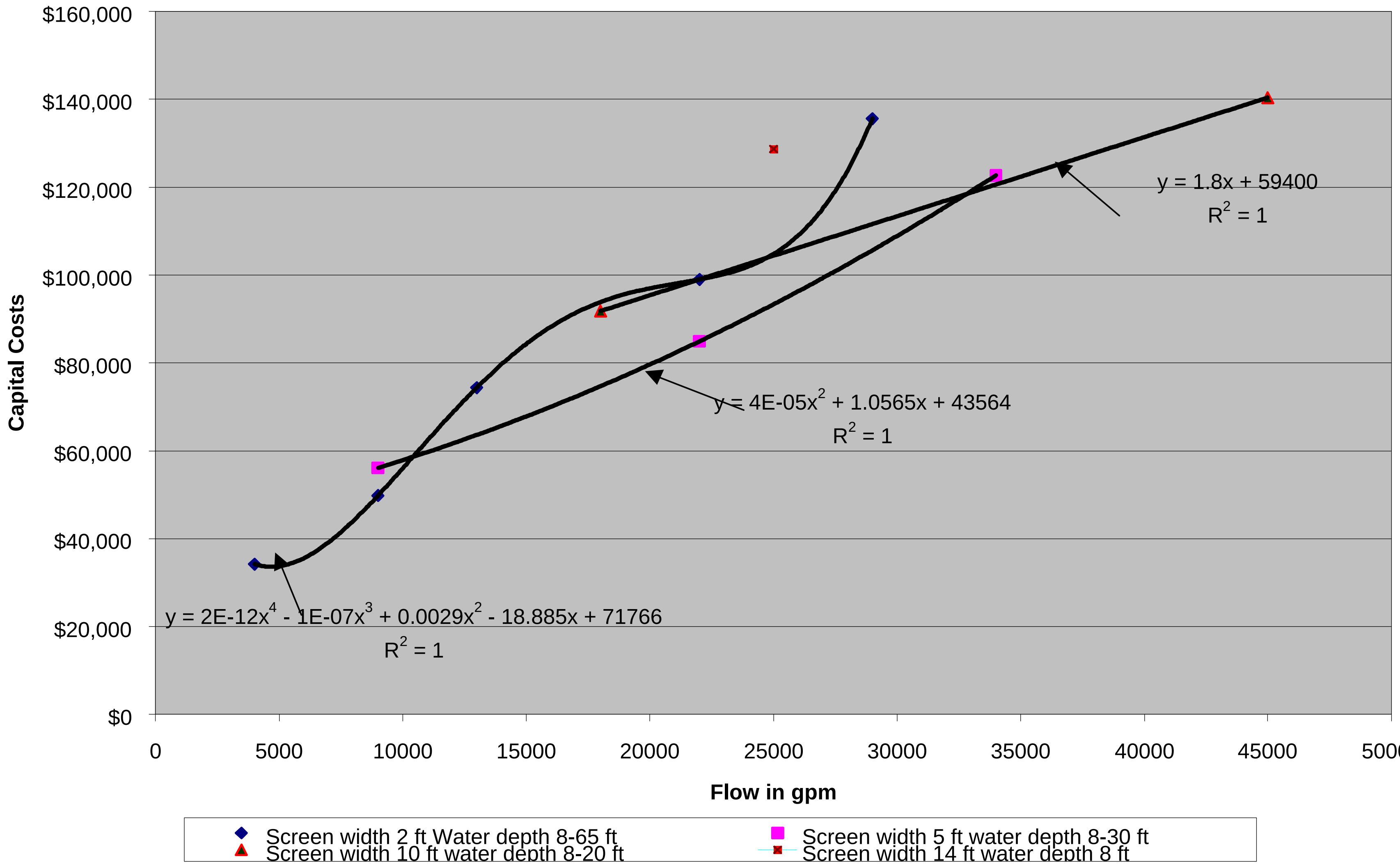


Chart 32. Velocity Caps Total Capital Costs

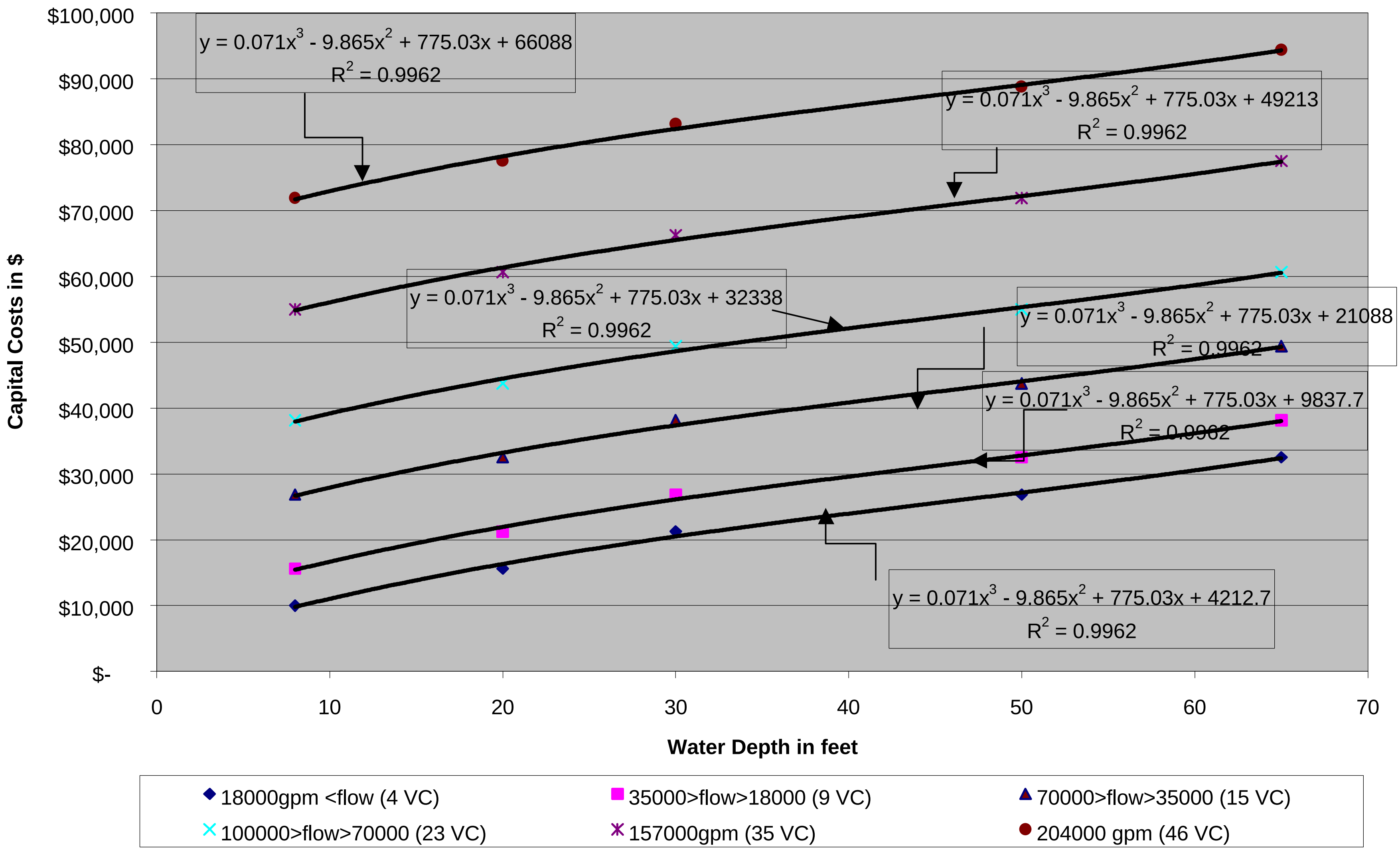


Chart 33. Concrete Fittings for Intake Flow Velocity Reduction

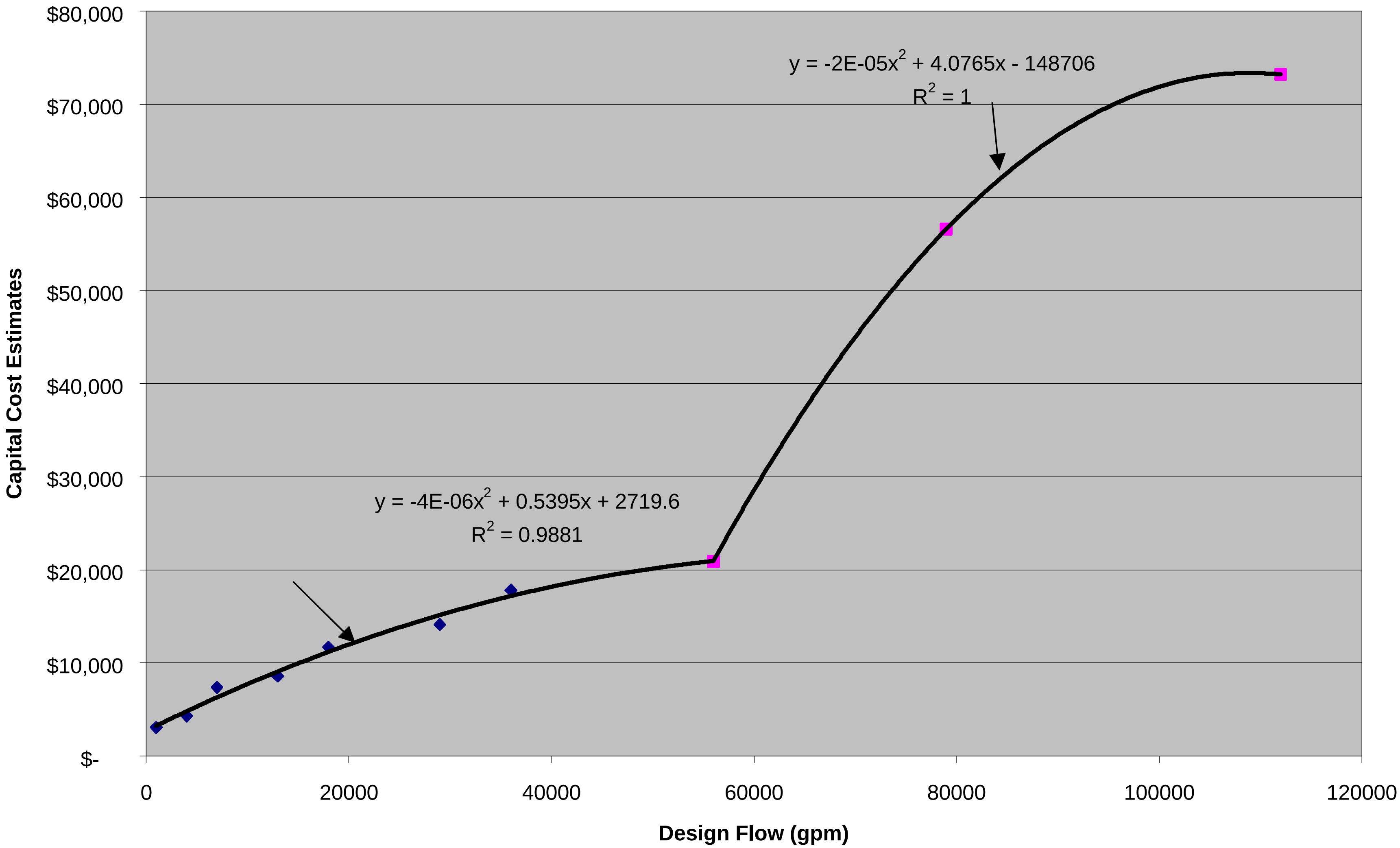


Chart 34. Steel Fittings for Intake Flow Velocity Reduction

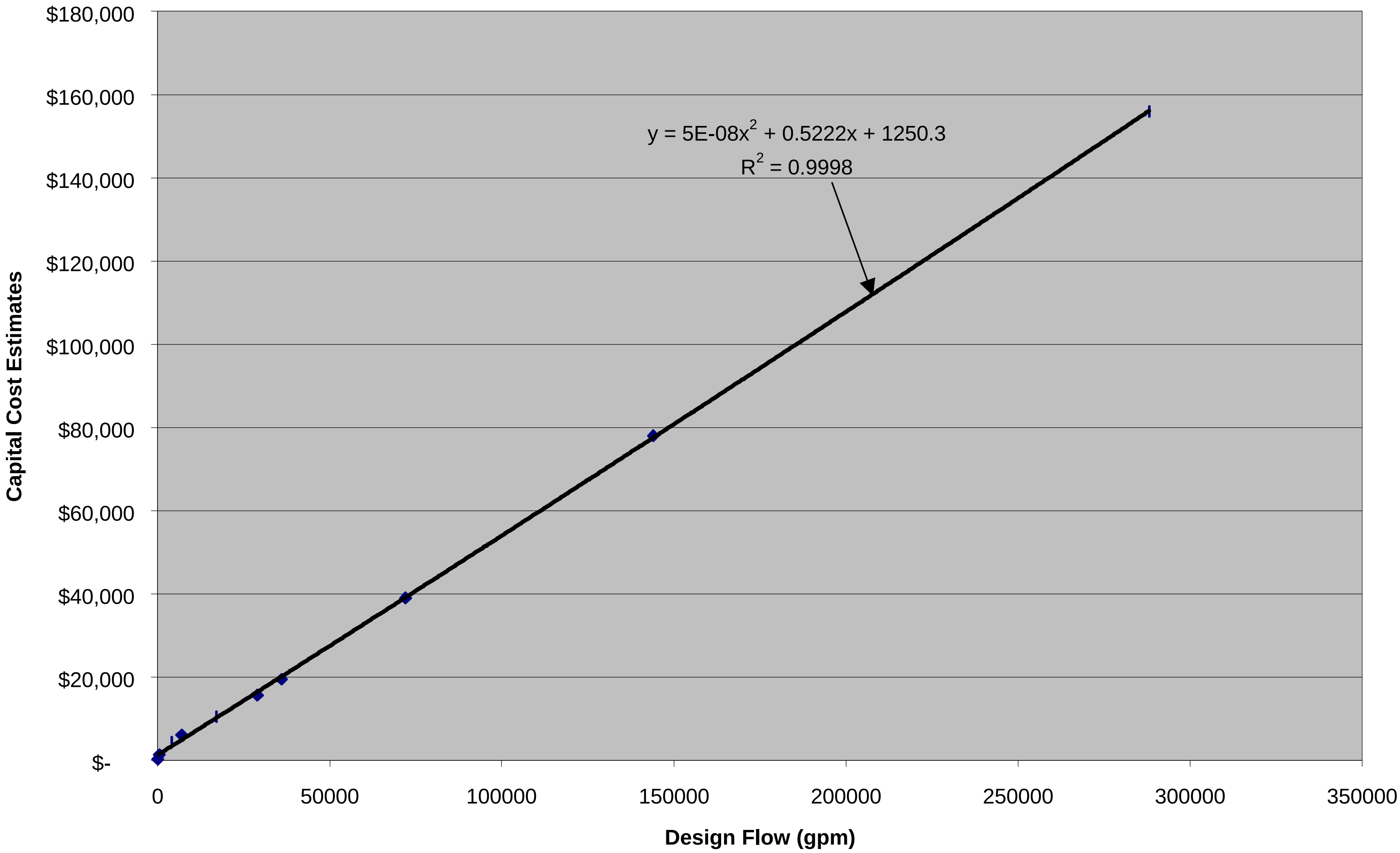


Chart 35. Travel Screens Capital Cost Without Fish Handling Features Flow Velocity 0.5ft/sec

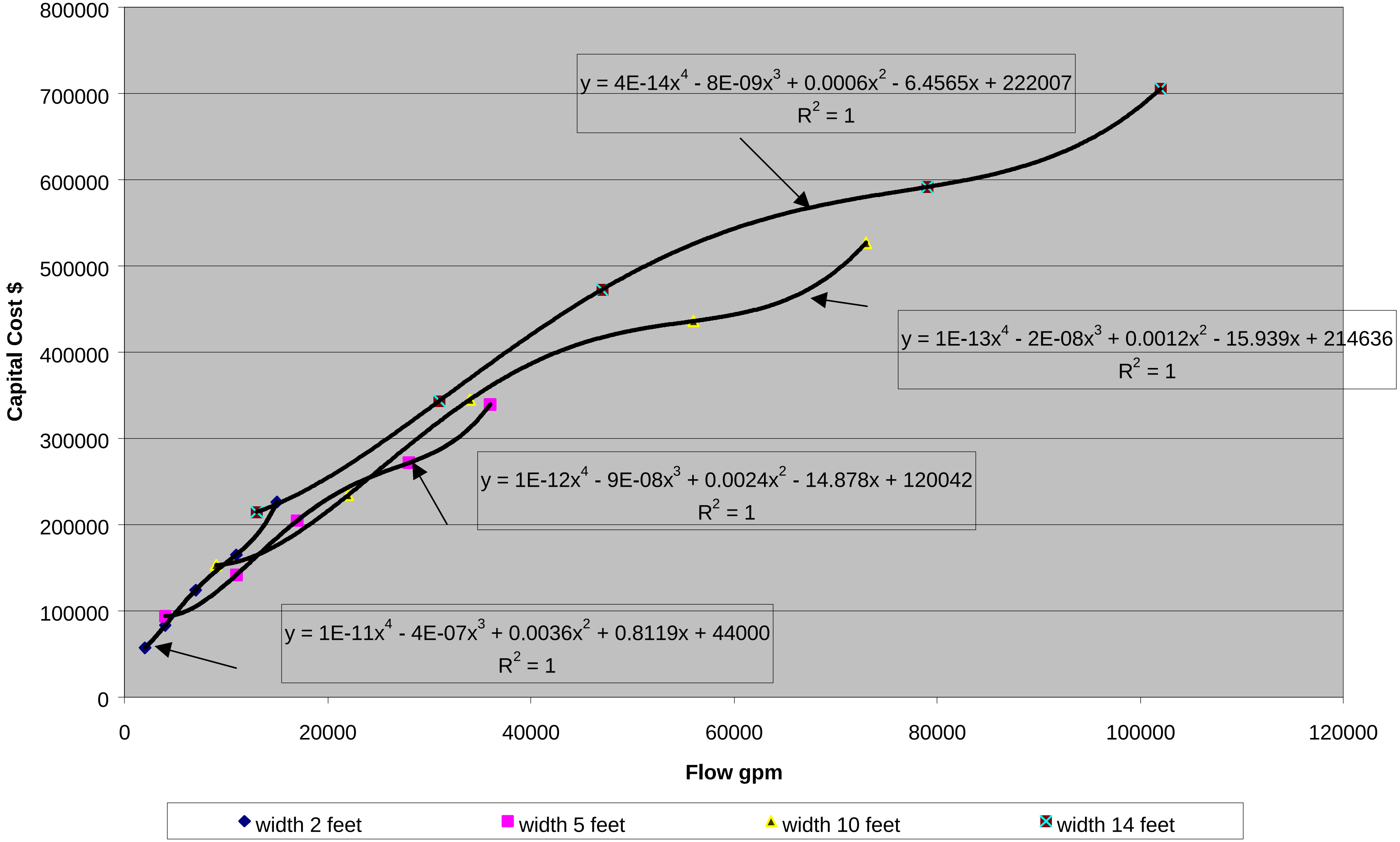


Chart 36. Travel Screens Capital Cost With Fish Handling Features Flow Velocity 0.5ft/sec

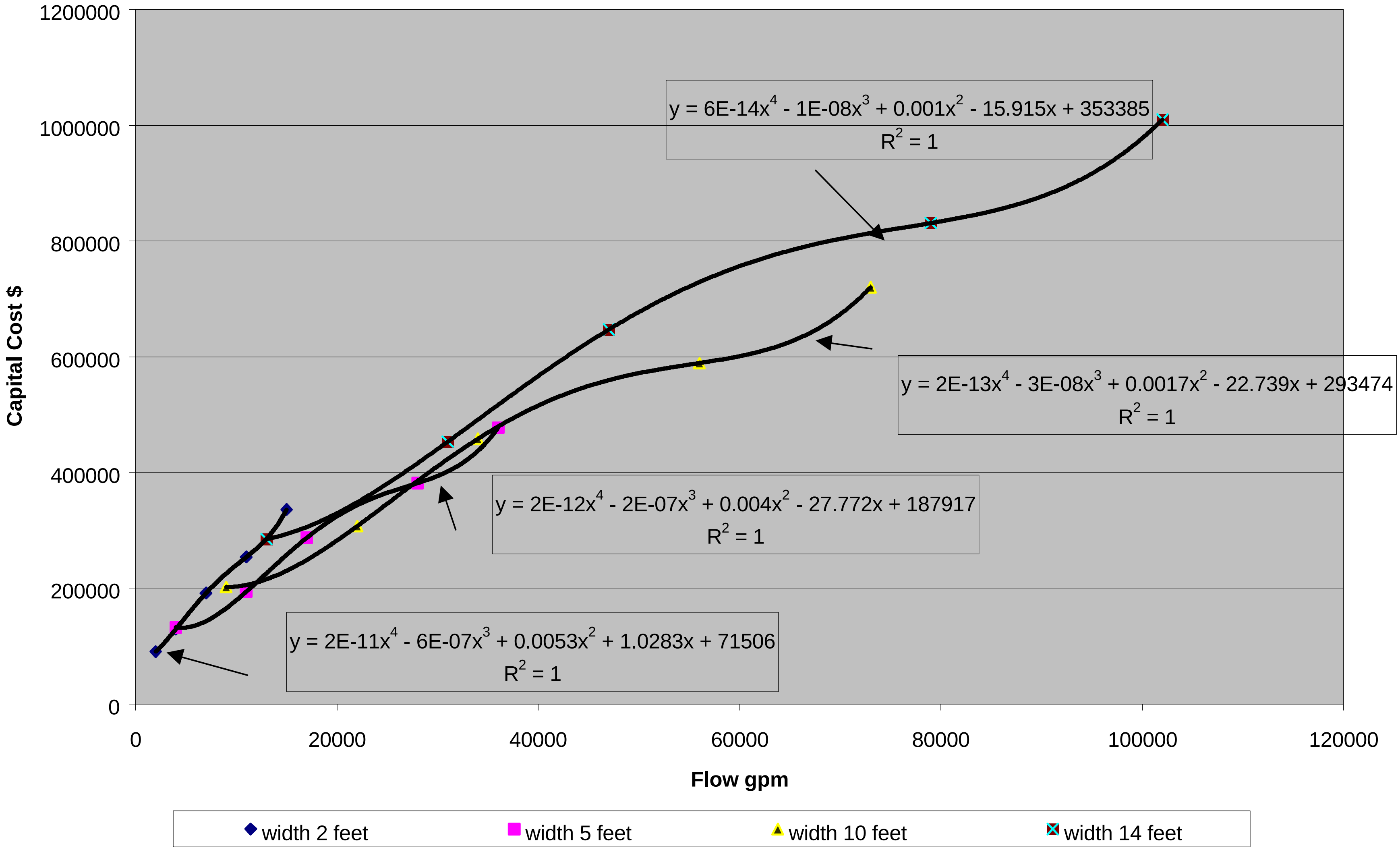


Chart 37. Travel Screens Capital Cost Without Fish Handling Features Flow Velocity 1 ft/sec

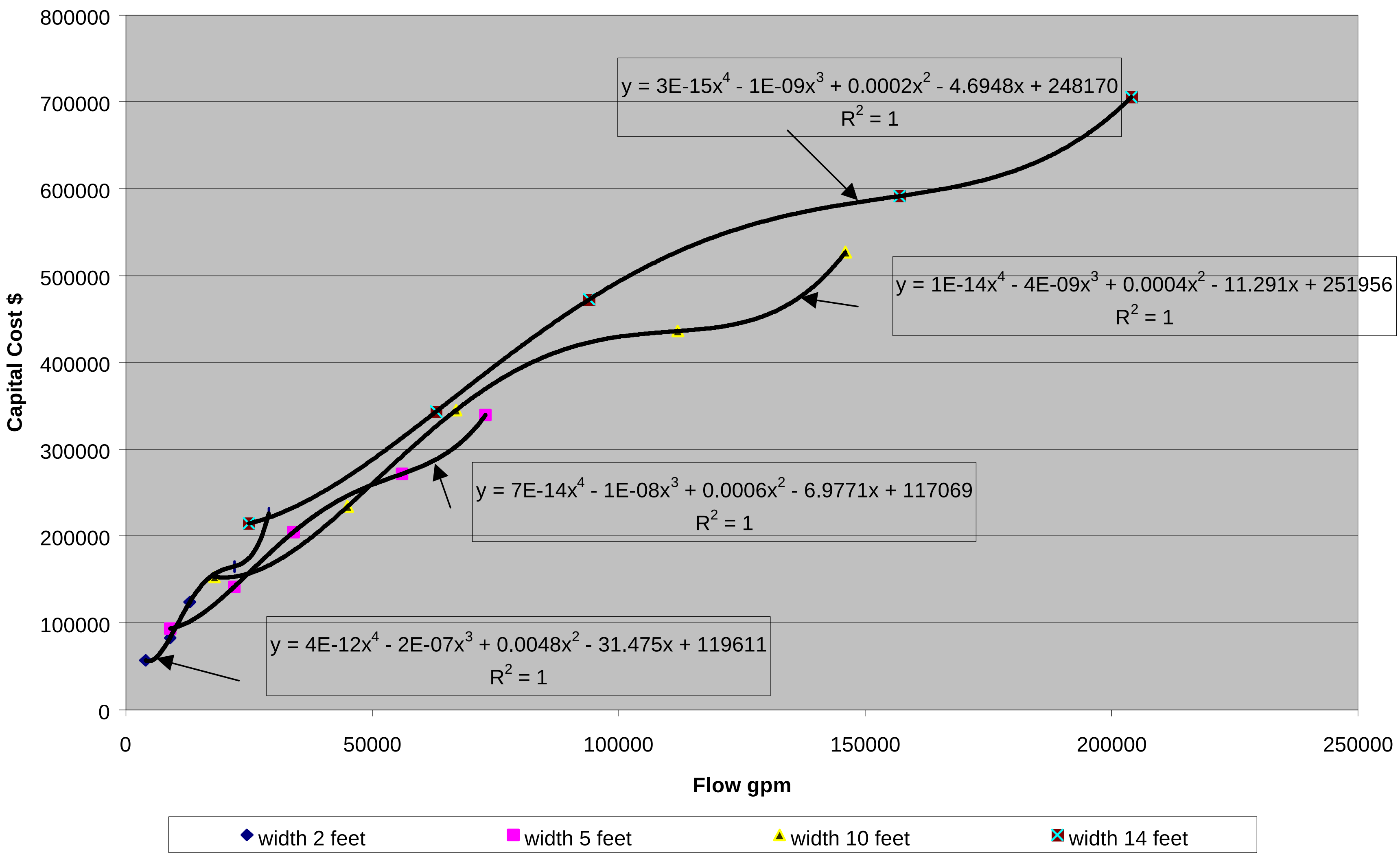


Chart 38. Travel Screens Capital Cost With Fish Handling Features Flow Velocity 1 ft/sec

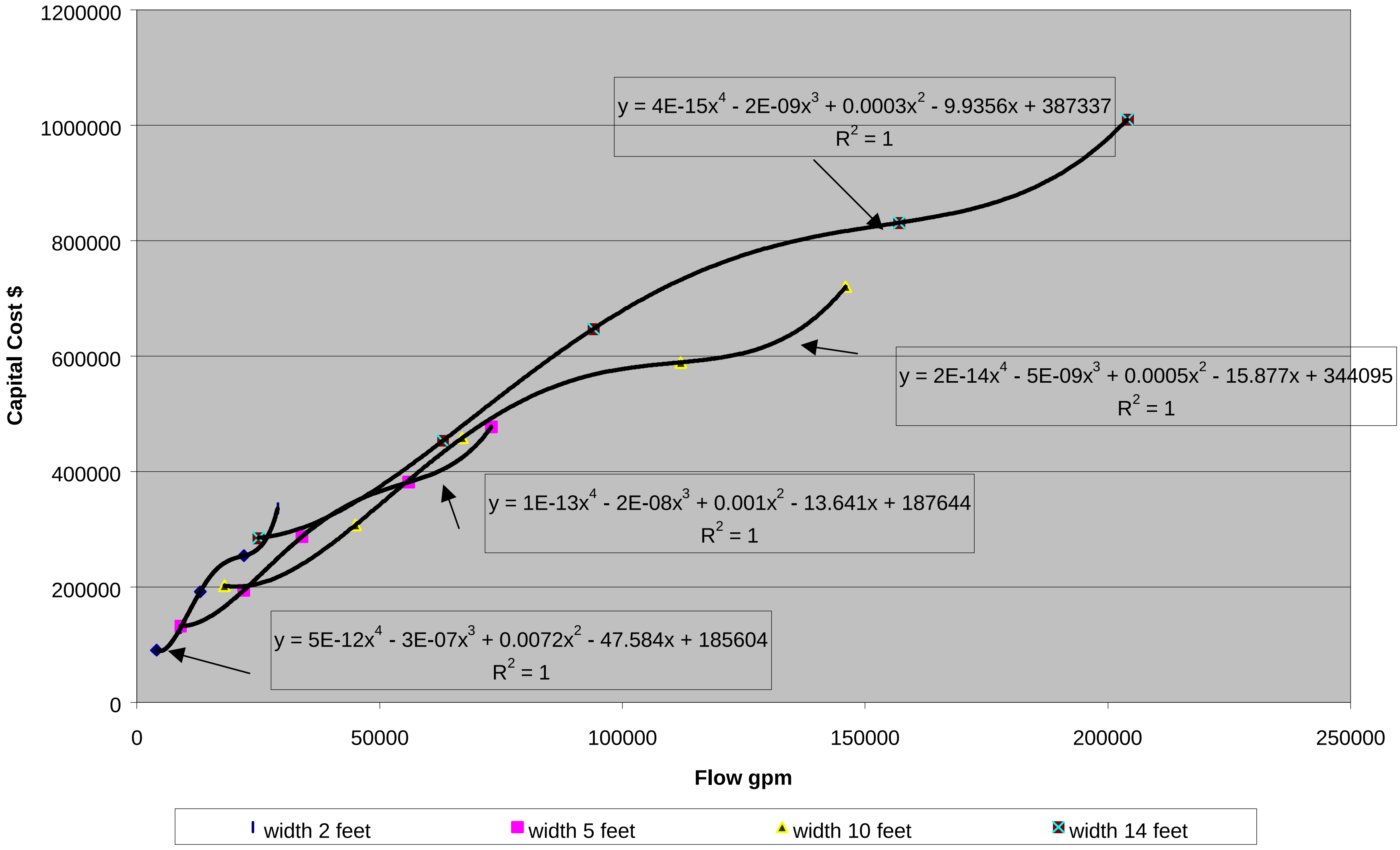


Chart 39. Fish Spray Pumps Capital Costs

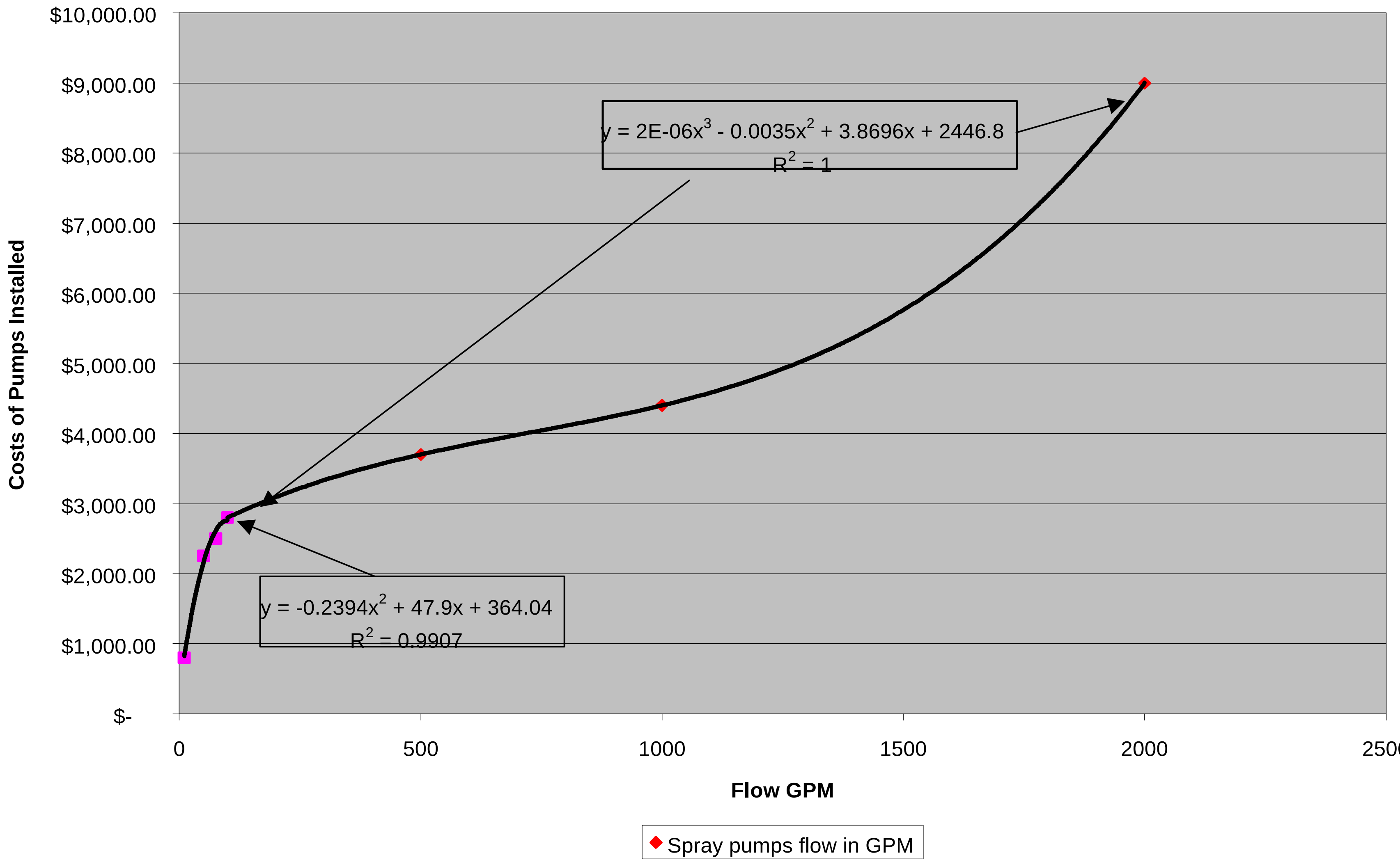


Chart 40. O&M Cost for Traveling Screens Without Fish Handling Features Flow Velocity 0.5ft/sec

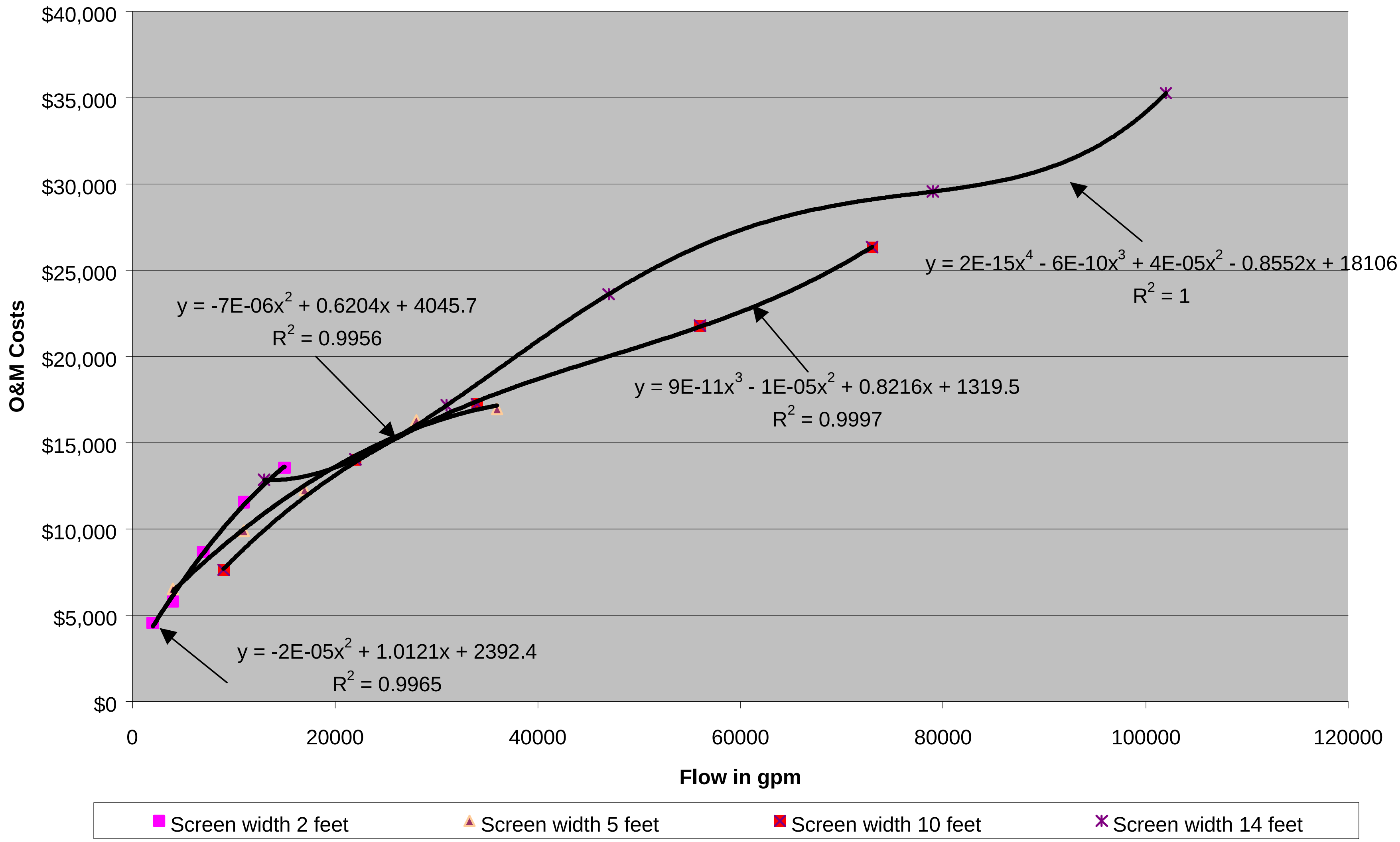


Chart 41. O&M Cost for Traveling Screens With Fish Handling Features Flow Velocity 0.5ft/sec

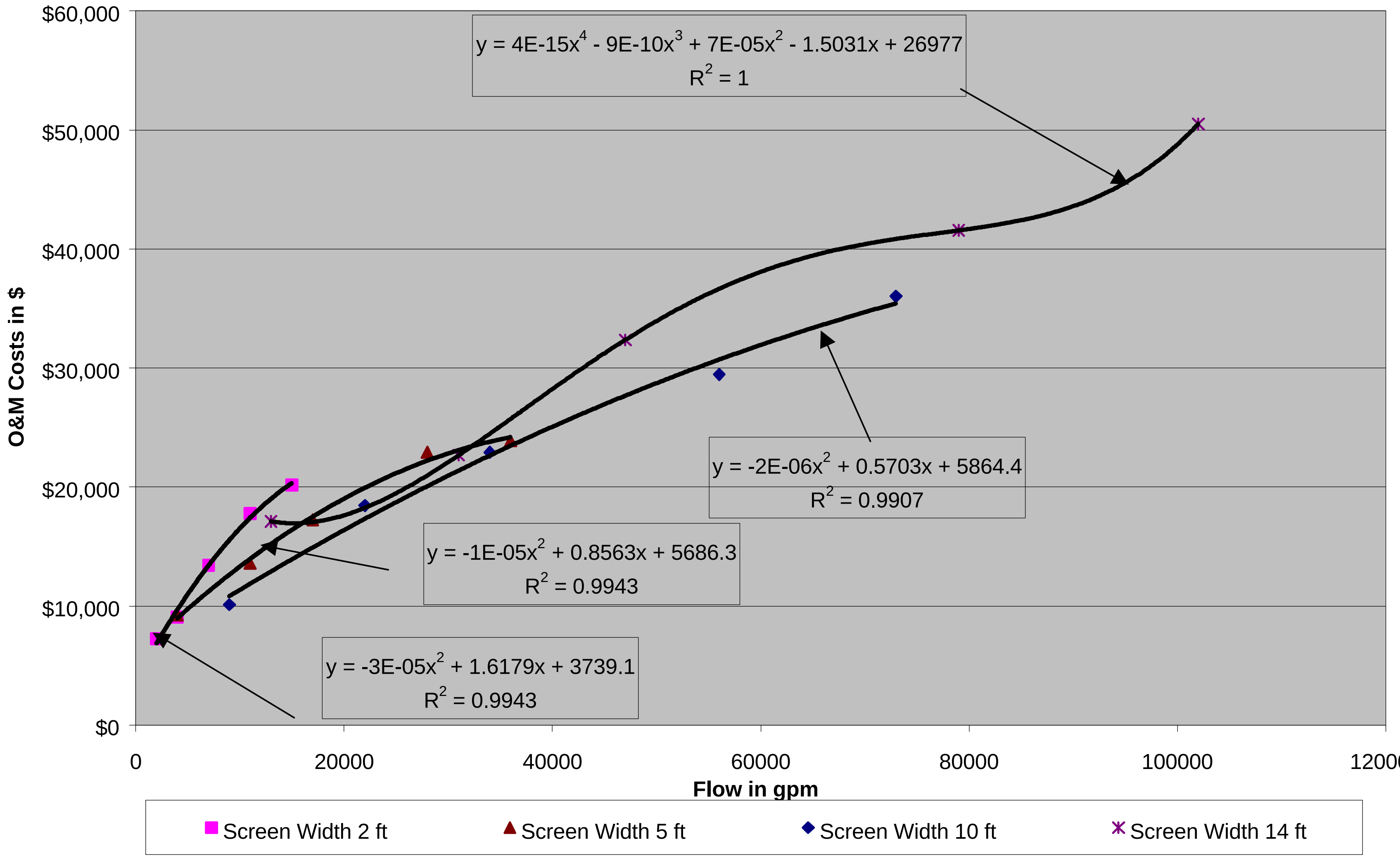


Chart 42. O&M Cost for Traveling Screens Without Fish Handling Features Flow Velocity 1 ft/sec

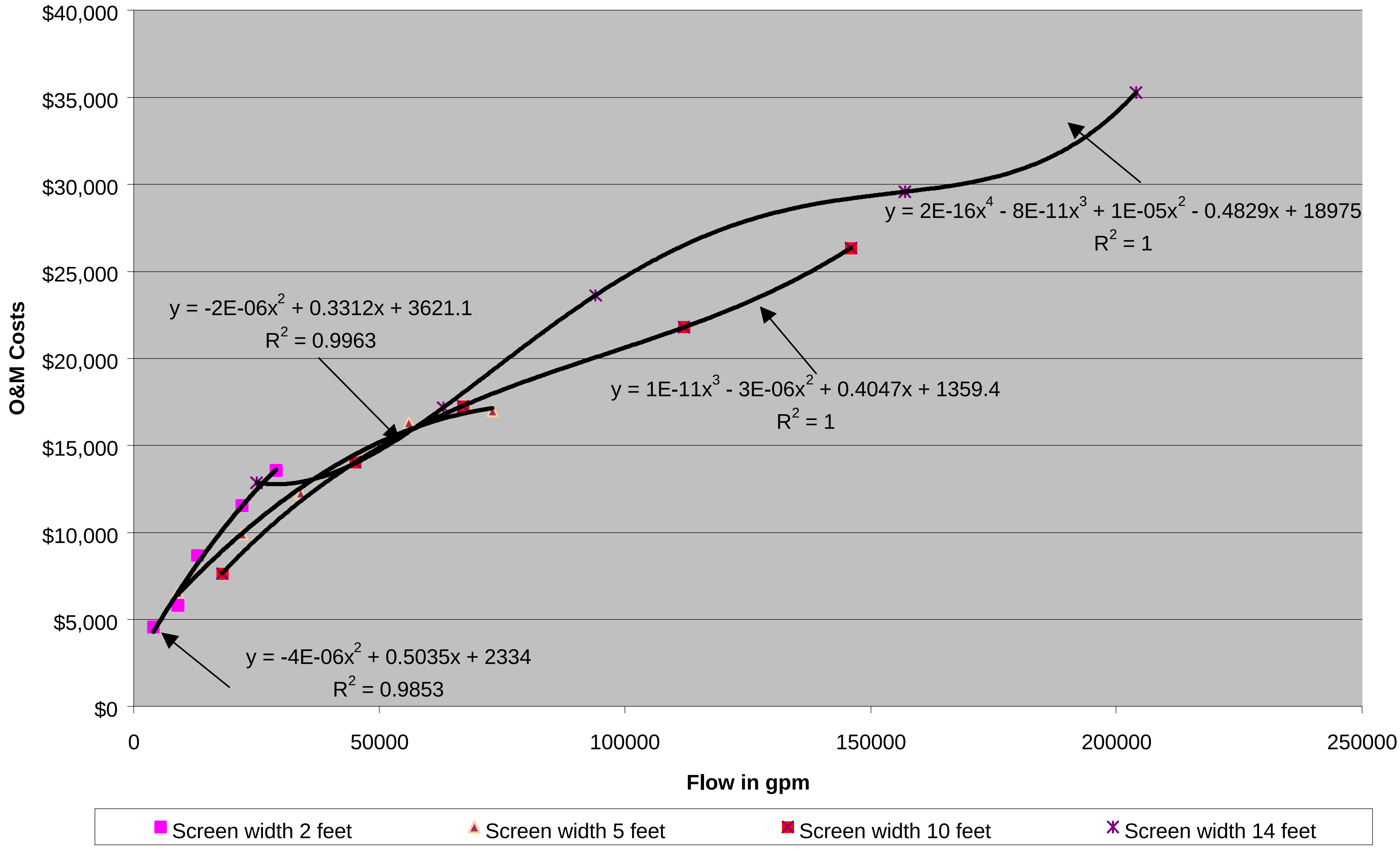


Chart 43. O&M Cost for Traveling Screens With Fish Handling Features Flow Velocity 1 ft/sec

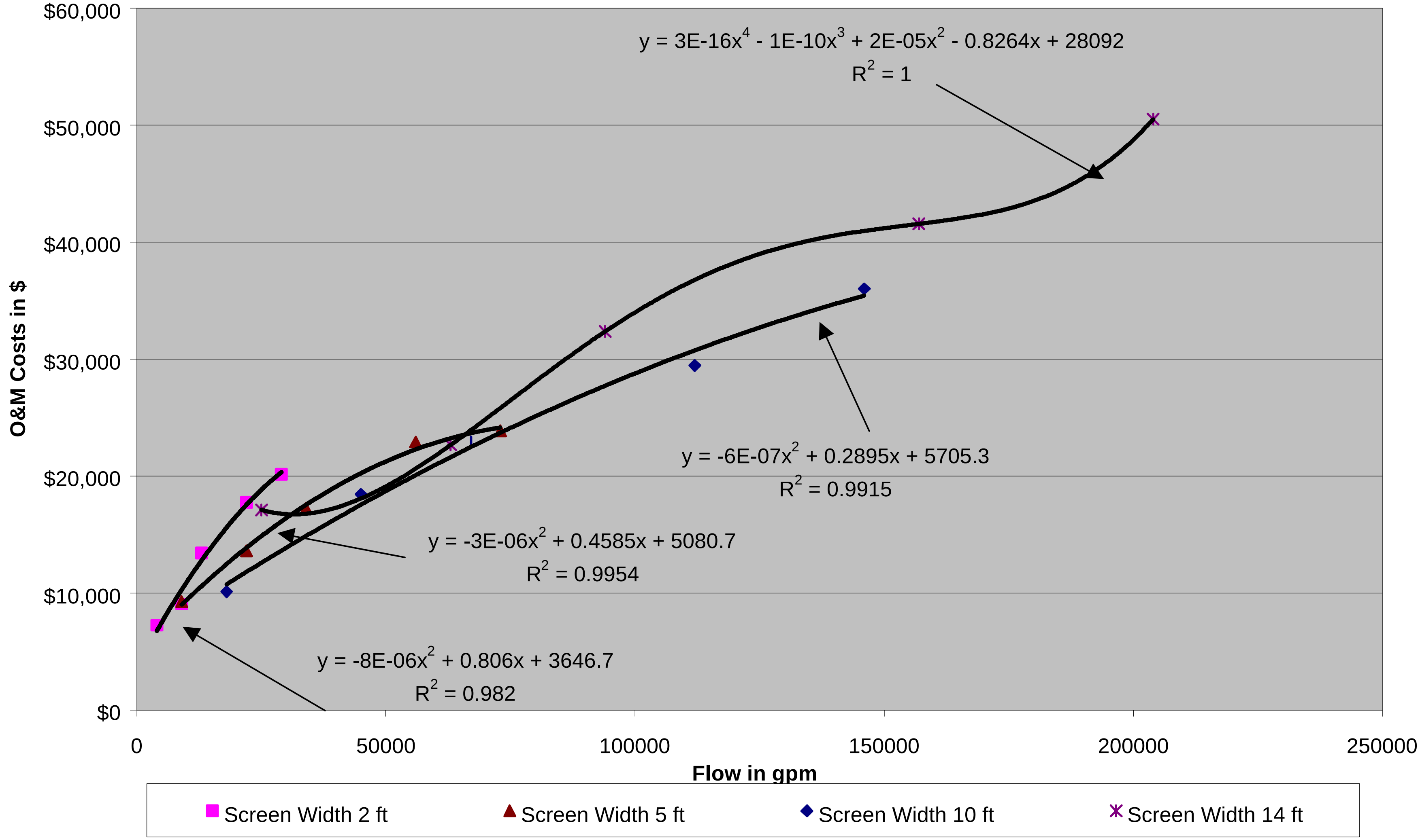


Chart 44. Capital Cost of Fish Handling Equipment Screen Flow Velocity 0.5 ft/sec

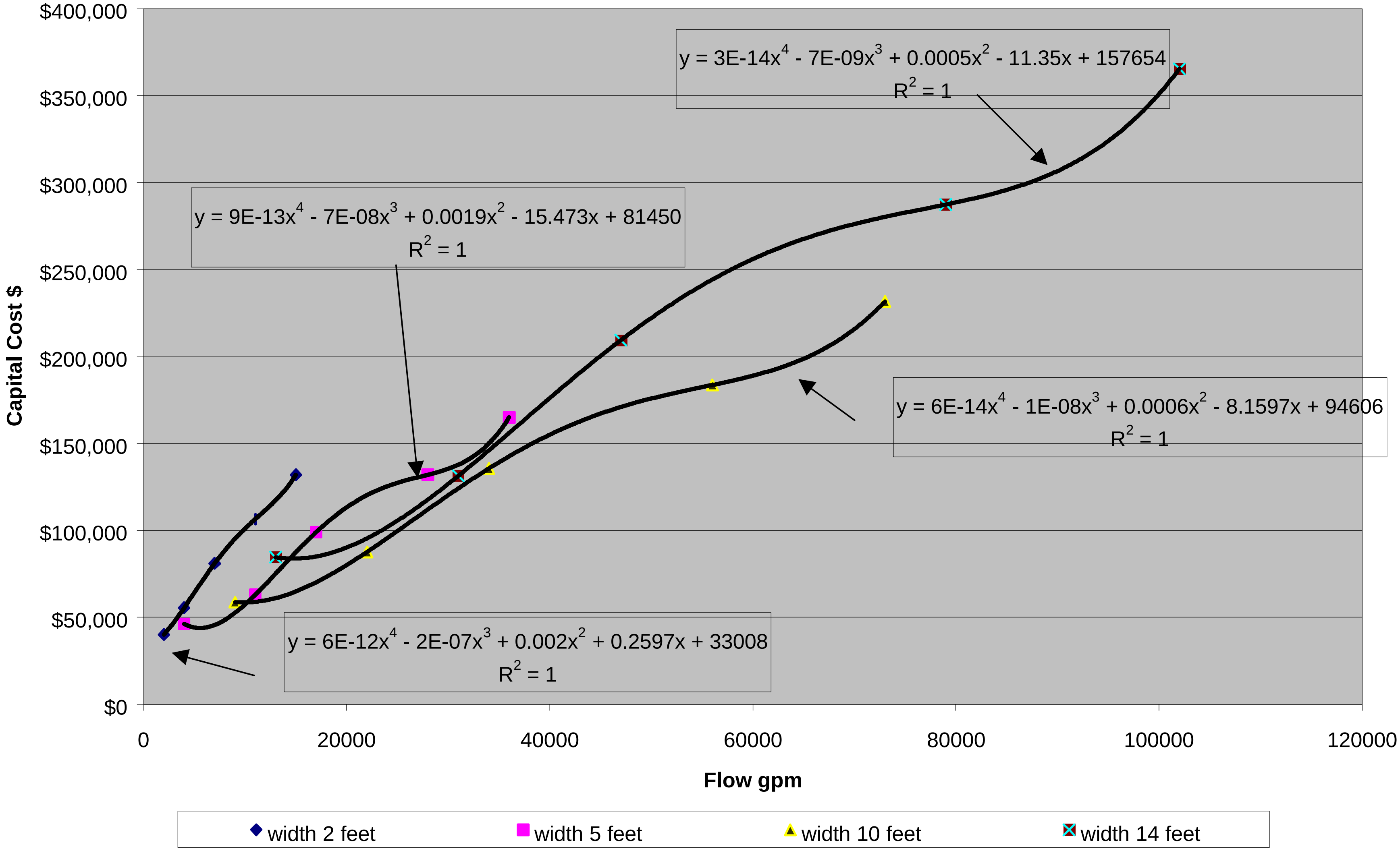


Chart 45. O&M Cost for Fish Handling Features Flow Velocity 0.5ft/sec