Transitioning to Non-Metal Antifouling Paints On Marine Recreational Boats in San Diego Bay

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Final Report

November 15, 2002

Submitted under Agreement No. 01-106-068
Between University of California and California Department of Boating and Waterways
Pursuant to California Senate Bill 315 Passed in 2001

TABLE OF CONTENTS

APPENDICES AND FIGURES

I. EXECUTIVE SUMMARY

Background

Concentrations of dissolved copper that exceed government regulatory standards are being detected in Shelter Island Yacht Basin of San Diego Bay and in Newport Bay in southern California, as well as in marinas and harbors of Chesapeake Bay in Maryland, of Port Canaveral and Indian River Lagoon in Florida, and in areas of Washington. Dissolved copper levels in America's Cup Harbor, Harbor Island, the Marriott Marina, and the Laurel Street area of San Diego Bay, in Dana Point Harbor and in Oceanside Harbor have also been proposed for regulatory attention. Pleasure craft antifouling paints contribute to high dissolved copper levels in these waters.

Copper based hull coatings are used to reduce fouling growth that slows sailboats and increases fuel consumption by powerboats. They retard the growth of algae, barnacles, tubeworms, and other species by slowly releasing dissolved cuprous oxide. The 2001 draft report of the California Regional Water Quality Control Board, San Diego Region's Total Maximum Daily Load study attributed 93% of the dissolved copper found in Shelter Island Yacht Basin to antifouling paints. The copper based antifouling paints replaced the much more toxic tributyl tin based paints that were banned for use on most recreational boats by the U.S. Environmental Protection Agency in 1987. Scientific studies have found that dissolved copper is harmful to mussels, oysters, scallops, sea urchins and crustaceans at levels similar to those found in boat basins of San Diego Bay and Newport Bay.

Copper-based hull coatings have been banned for use on recreational boats in parts of the Netherlands, Sweden and Denmark. The European Union has asked the International Maritime Organization to ban all toxic boat bottom paints. The U.S. EPA's and California's nonpoint source pollution policies recommend nontoxic bottom paints for recreational boats and California has also mandated the phase-out of toxic hull paints on state and local government vessels. The California Regional Water Quality Control Board, San Diego Region is considering regulations to reduce the level of dissolved copper in Shelter Island Yacht Basin; regulations will probably include nontoxic paints as an alternative for reducing copper pollution from boats.

Nontoxic alternatives to commonly used copper hull coatings can greatly reduce, and in some cases eliminate, copper contamination associated with recreational boats. A variety of different policy options are available to mandate or provide economic incentives to switch to these less harmful alternatives. These options are proposed and evaluated for use in San Diego Bay. A conceptual framework for evaluating policies to transition to these alternatives is put forth in terms of copper concentrations and costs to boat owners. Impacts on other parties such as boatyards, hull cleaners, and marinas are also considered.

Objectives Considered

Two objectives are formally considered: the 66% reduction in copper contained in the California Regional Water Quality Control Board, San Diego Region's draft TMDL, and a complete phase-out of copper based hull paints on recreational boats in San Diego Bay.

Findings: Hull Coating Suitability

Six types of boat hull coatings were considered: traditional (high) copper, low copper, silicone, hard epoxy, epoxy with fibers, and epoxy with embedded copper flakes.

Low copper paints failed as a method of achieving either objective because they lose similar amounts of copper in the water over time as traditional copper paints. This is because low copper paints either require more initial coats of paint or last a shorter period of time.

Hard epoxy paints from a technical perspective are an adequate substitute for traditional copper paints. They have the advantage of lasting longer than copper hull paints and the disadvantage of requiring more frequent hull cleanings. Most of the analysis in this report is based upon a comparison of traditional copper and hard epoxy paints.

Epoxy with fibers failed in our demonstration project and thus was not considered further. No example of the class of epoxy paint with embedded copper flakes is currently licensed for use in California, so we were unable to obtain any local test data for this type of paint. Hence this option was also not considered further, although it may be a viable one in the future.

Silicone paints are well suited for some specialized applications, such as racing powerboats, because silicone tends to increase the speed of a boat and frequent use of the boat at high speeds tends to clean the hull. Initial formulations of silicone paints had fairly severe difficulties if applied to boats that were not used frequently at high speeds (which characterizes most recreational boats) because they were fairly unforgiving with respect to the need for frequent hull cleaning. Limited experience with the next generation of silicone paints suggests that some of these problems have been overcome and some variant of silicone is likely to be a promising option in the future.

Findings: Cost and Implementation Issues

Hull maintenance cost issues from the perspective of a boat owner revolve around: (a) the cost of applying a hull coating, (b) the frequency with which a hull coating needs to be applied, (c) how often old paint needs to be stripped off, and (d) hull cleaning costs.

Because of the difference in how often a boat needs to be repainted and stripped, the cost comparison between copper and non-toxic paints needs to be made in terms of the total lifetime hull maintenance cost for the boat.

Copper paint is currently less expensive to apply than non-toxic paints (although the gap between the two would be expected to decrease over time, particularly if non-toxics were applied on a large scale). Copper paints have to be applied more often than non-toxic paints and need to be stripped off periodically at around every sixth application. They have lower hull cleaning costs because they are specifically formulated to retard hull fouling. If one assumes that the actual paint application costs converge to the same level, the maintenance cost tradeoff between copper and non-toxics is one of frequency of hull painting (including the need to strip) versus hull cleaning.

A key issue with non-toxic paints is the need to have a “new” or “stripped” hull before such a paint can be applied. Stripping is expensive but some boats need to be stripped anyway because of too much paint build-up. Thus new boats and boats that need to be or are close to needing to be stripped will be the most favorable candidates for non-toxic paint application in terms of a non-toxic/ copper cost comparison.

The ability to apply new coats of paint over copper paint multiple times before the need to strip the hull is effectively an asset that is depreciated over time until all of the old copper paint needs to be stripped off. Stripping a boat that has been recently painted and converting it to a non-toxic hull coating dramatically increases total lifetime hull maintenance costs.

Total lifetime hull maintenance costs are most favorable to non-toxic paints when they are applied either initially to a new boat hull or to an existing boat hull that needs to be stripped of its old copper paint.

Finding: Hull Cleaning Practices

It is clear that hull cleaning practices can have an important influence on the long-term rate of copper leaching into the water from recreational boats. At present, however, insufficient information exists to provide guidance on the desirability of implementing specific hull cleaning practices with respect to copper losses.

Findings: Boat Owners’ Perceptions

Boat owners have limited knowledge of the nature of the copper problem in San Diego Bay and of non-toxic alternatives. This suggests that an educational campaign is likely to be a useful component of any effort to move from copper to non-toxic hull coatings.

The average boat owner is willing to pay a moderate size premium of around $500 for non-toxic paint rather than copper. Some boat owners are willing to pay substantially more, which suggests that with an educational activity there would be some movement toward non-toxic paints. However, many boat owners appear to place little or no independent value on the non-toxic nature of alternative hull coatings. This suggests that, without a strong cost advantage, the use of copper paint will never be voluntarily phased out.

The most effective instrument for currently moving boat owners to adopt non-toxic paints appears to be the presence of a future ban on the use of copper.

Finding: Barriers to Large-Scale Commercial Application

San Diego boatyards and hull cleaners currently possess insufficient knowledge and experience for successful implementation of any policy designed to meet one or both of the objectives. A two-year period is needed which focuses on moving from the current "proof of concept" demonstration project to a demonstration project centered on how to effectively move to the stage of efficient commercial application. The key objectives of the demonstration project are to increase capacity to apply non-toxic hull coatings and to reduce the cost of doing so.

Finding: Need for An Educational Component

This same two-year period could also be used to mount an educational effort. One of the main focuses of this effort should be on the long-term cost of hard non-toxic paints relative to copper paints. Over short time horizons, copper based paints have a clear cost advantage. However, when considering hull maintenance cost over the life of a boat, epoxy often looks like the lower cost alternative. One of the main results of this study is that traditional copper and epoxy paints are generally "close" from a cost perspective if epoxy is applied to new boats or boats that are close to needing to be stripped of their old paint.

Finding: Capacity Constraint Sets Minimum Conversion Time

Boatyard capacity constraints (related to the increased labor/time needed to strip off copper paint before applying non-toxic paint) prevent immediate conversion of the current fleet of recreational boats in San Diego Bay from copper to non-toxic paints. The quickest possible time in which the 66% reduction objective could be achieved (after large scale commercial application is viable) is five years, and a complete phase out is possible within 7 years.

Finding: Policies Achieving Minimum Conversion Time Have Very High Costs

Implementation of a quickest-time policy requires that all new boats use non-toxic hull paints and requires that boats with hulls painted with copper based paints be banned from San Diego Bay marinas and mooring locations at the end of the seven year period. Quickest-time policies are difficult to implement since they allow no room for delays or mistakes. They are either very expensive for boaters if forced to bear the cost directly or for government agencies if subsidies are used. The costs of these policies vary with the specific approach taken but are roughly in the range of twenty million dollars.

Finding: Policy Options Exist Which Take Longer But Have Much Lower Costs

The least cost policy can achieve the 66% reduction within 12 years and the complete phase out within 15 years. These policies also require that new boats be initially painted with non-toxics and that copper-hulled boats be banned at the end of the policy period. Favorable cost conditions for epoxy would result in the 66% reduction being met early.

The least cost policy can achieve the objectives at a cost of approximately one million dollars, as opposed to a cost of approximately twenty million dollars for policies achieving the objectives in roughly half the time.

It is possible to look at the policies that achieve the 66% reduction and complete phase out objectives in the quickest time, policies that achieve these objectives with the least cost, and policies that meet the objectives at times in between the two. Costs tend to fall substantially as one moves toward a 15 year time horizon.

Findings: Policy Instruments

The most important single policy instrument is a requirement that new boats use only non-toxic paints. This will begin the phase-out of copper and will save the boat owner money (looked at from a total lifetime hull maintenance cost perspective) under plausible assumptions about the cost and performance of non-toxic paints.

The second most important policy instrument is a ban on the use of copper paint at some future date. This makes boats with non-toxic hull coatings more valuable and has a large influence on whether to repaint with copper or non-toxics at the time an existing boat's hull is being stripped.

Among economic instruments for giving boat owners an incentive to convert to non-toxics, a marketable copper quota that declines over time is the most effective and the most flexible. This instrument can also be used to ensure that a program stays on track. Other standard economic policy instruments, such as user fees on copper paint and various types of subsidies, suffer from the problem of not being able to selectively target boats at specific times in their lifecycle, which makes these policies fairly inefficient.

II. Introduction

This report addresses the implications of potential policies to reduce the use of copper in hull coatings on recreational boats in San Diego Bay. It is being conducted under a contract to the University of California (Sea Grant Extension Program and the UCSD Department of Economics) by the California Department of Boating and Waterways pursuant to California Senate Bill 315.

Copper based hull coatings are used to reduce fouling growth that slows sailboats and increases fuel consumption by powerboats. They retard the growth of algae, barnacles, tubeworms, and other species by slowly releasing cuprous oxide that enters water and sediments of boat basins. The copper based antifouling paints replaced the much more toxic tributyl tin based paints, which were banned for use on most recreational boats by the U.S. Environmental Protection Agency in 1987. Dissolved copper levels in boat basins of San Diego Bay and Newport Bay in southern California range from 2.6 to 29.0 parts per billion (ppb), according to the California Regional Water Quality Control Board, San Diego Region (2001) and the California Regional Water Quality Control Board, Santa Ana Region (2000). The federal and state regulatory standard for dissolved copper is 3.1 ppb (U.S. EPA 2000).

The 2001 draft report of the San Diego Regional Board's Total Maximum Daily Load (TMDL) study found that 93% of the dissolved copper in Shelter Island Yacht Basin came from passive leaching and hull cleaning of antifouling paints of recreational boats. The U.S. EPA's (2002a) TMDL study reached similar conclusions for Newport Bay. Dana Point Harbor has been proposed for California State Water Resource Control Board's (SWRCB's) 303(d) List of Impaired Waterbodies (California SWRCB 2002a) because of dissolved copper and as a high priority for a TMDL study. America's Cup

Harbor, the area near Laurel Street (where pleasure craft moor), Harbor Island and the Marriott Marina (all in San Diego Bay) and Oceanside Harbor have been proposed for California SWRCB's 303(d) Monitoring List (California SWRCB 2002b) because of dissolved copper.

Scientific studies of mussels, oysters, scallops, sea urchins and crustaceans have found that dissolved copper at levels found in the studies of San Diego Bay and Newport Bay affects them at various life stages. When exposed to dissolved copper at concentrations from 3.0 to 10.0 ppb, various species showed reduced or abnormal: embryo growth, development, swimming and survival; larval growth and survival; adult growth, spawning and survival; and adult digestive, reproductive and muscle tissues (Calabrese et al. 1984; Coglianese and Martin 1981; Gould et al. 1988; Lee and Xu 1984; Lussier et al. 1985; MacDonald et al. 1988; Martin et al. 1981; Redpath 1985; Stromgren and Nielsen 1991). Some of these studies and others (Krishnakumar et al. 1990; Redpath and Davenport 1988) found that many of the above effects became more severe and that feeding, respiration, and waste elimination of adult mussels were also affected at dissolved copper levels from 10.0 to 29.0 ppb.

Dissolved copper also exceeds state standards in marinas and harbors: of Chesapeake Bay, Maryland (Hall et al. 1988); at Port Canaveral and Indian River Lagoon, Florida (Sheffield Engineering 1998; Trocine and Trefry 1993); and in areas of Washington (Washington State Department of Ecology 1999). Pleasure craft bottom paints and boatyard runoff contribute to high dissolved copper levels in these waters (Washington State Department of Ecology 1999; Hall et al. 1988; Srinivasan 2001).

Further, parts of Europe have already banned the use of copper based hull coatings for recreational vessels. Along the east coast of Sweden (Swedish National

Chemicals Inspectorate – KEMI 1998), in the Netherlands, and in Denmark's freshwater areas, copper-based antifouling paints have been banned for use on recreational vessels (Watermann 1999). Members of the European Union are implementing the Biocidal Products Directive (BPD) that took effect in May 2000. The BPD regulates pesticide production, including antifouling paint, and requires that biocides be authorized and proven safe in laboratory and field experiments (European Parliament and Council of the European Union 1998).

Sweden, Finland, Germany, France, and the United Kingdom are monitoring dissolved copper in coastal and inland waters. The European Union has asked the International Maritime Organization to ban all toxic boat bottom paints. (European Union Environmental Action Programme 2001). Sweden, Finland, and the United Kingdom are reviewing their antifouling policies with regard to copper pollution (Swedish Maritime Administration 2002; Nash 2002; United Kingdom Pesticide Safety Directorate 2002).

In response to the high copper levels in southern California harbors and bays, the California Regional Water Quality Control Board, San Diego Region and the U.S. EPA are conducting Total Maximum Daily Load programs for Shelter Island Yacht Basin in San Diego Bay (CRWQCB,SDR 2001) and Newport Bay (U.S. EPA 2002a) to determine how much copper is present and how much can be allowed. Technical studies have been completed and regulations to reduce copper levels are being planned. Regulations will probably include nontoxic paints as an alternative for reducing copper pollution from boats.

The U.S. EPA's *Management Measures to Control Nonpoint Source Pollution* already recommends less toxic or nontoxic antifouling paints (U.S. EPA 2002b). California's *Plan for Nonpoint Source Pollution Control* also recommends nontoxic products, such as bottom paints, for boat maintenance and mandates that toxic hull paints be phased out for state and local government vessels. (CSWRCB 2000)

Overall, severe U.S. restrictions on the use of copper in antifouling paints within five years have been predicted by marine market analysts, due to increasing public concern about the environmental effects of copper-based paints. To prepare for this, every major paint company is studying biocide-free paints. (Kettlewell 2000)

Nontoxic alternatives to commonly used copper hull coatings can greatly reduce, and in some cases eliminate, copper contamination associated with recreational boats. A variety of different policy options are available to mandate or provide economic incentives to switch to these less harmful alternatives. These options are proposed and evaluated for use in San Diego Bay. A conceptual framework for evaluating policies to transition to these alternatives is put forth in terms of copper concentrations and costs to boat owners. Impacts on other parties such as boatyards, hull cleaners, and marinas are also considered.

The San Diego Advisory Committee for Environmentally Superior Antifouling Paints, which was established for this project under California Senate Bill 315, met several times with the authors of this report and provided valuable input both as a committee and as individuals. The authors wish to thank them as well as numerous other individuals in the boating community who provided assistance in conducting this study. The analysis and the findings put forth in this report do not necessarily represent the views of anyone other than the authors.

III. Basic Assumptions

Policy Objectives and Evaluation Criteria

To evaluate possible policies toward copper-based hull coatings on recreational boats in San Diego Bay, it is first necessary to specify what the policy objectives and criteria are for evaluating the merits of a specific policy. Following the language of California Senate Bill 315, we look at two complementary policy objectives:

(1) Development of a plan that meets the California Regional Water Quality Control Board, San Diego Region's proposed (April 23, 2001) Total Daily Maximum Loading (TDML) requirement of a 66% reduction in dissolved copper coming from recreational boats in Shelter Island Yacht Basin.

(2) Development of a plan that results in the eventual phase-out of copper-based hull coatings on recreational boats in San Diego Bay.

Any phase-out of the use of copper-based hull coatings will require that the 66% reduction required by the Regional Board's TDML be met first. In this sense, the Regional Board's objective of a 66% reduction in current dissolved copper coming from recreational boats can be seen as either an intermediate step toward a final phase-out or as a final policy end point. This report assumes that the Regional Board's TDML is legally required to meet water quality standards and that it is beyond the scope of this report to examine the desirability of completely phasing out the use of copper-based recreational boat hull coatings.

Potential policies will be examined and a determination made as to whether they have the potential to be used to meet the Regional Board's 66% reduction in dissolved copper, and, if met, whether that policy can also be used to accomplish a complete phase-out of the use of copper-based hull coatings on recreational boats. These policies are examined with respect to three main criteria:

(1) costs to recreational boat owners,

(2) the burden placed on other relevant parties, and

(3) the reduction in copper from recreational boats at different points in time.

Policies that have lower costs, place lower burdens on other relevant parties, and reduce copper more quickly are assumed preferred.[1] A policy is considered dominated by another policy if it is inferior to that policy on all three dimensions. Otherwise, different stakeholders may place different weights on these criteria, and hence, judge different policies preferable. The "other relevant parties" considered are boatyards, hull cleaners, marinas, the San Diego Unified Port District and the State of California. A policy that cannot be used to meet one of the two specified objectives within a specified time period will be termed infeasible with respect to that objective and time period.

Geographic Scope and Implementation

The geographic area considered in this study is San Diego Bay. This scope is consistent with California Senate Bill 315. It is broader, however, than the draft TMDL of the Regional Board which covers Shelter Island Yacht Basin, although the Regional Board is currently studying potential copper problems in other parts of San Diego Bay. The mathematical formulas used in the draft TMDL suggest that problems with dissolved copper will exist any place where there are a sufficiently large number of recreational boats (as the basic source of copper is simply leaching from the hull coatings of boats in yacht slips and mooring locations). The other major factor influencing dissolved copper

[1] A broader analysis would look at both the benefits and costs associated with meeting specific objectives. This report only looks at the cost of meeting particular objectives. As such, statements about the net benefits of particular policies cannot be directly inferred from this report without some external source of benefit estimates. The framework taken in this report is one of cost effectiveness, which is what economists usually look at when the policy objective is already specified by legislative or legal mandate.

levels is the nature of water circulation. Water circulation at other boat basins within San Diego Bay is generally low and hence more conducive to a copper problem, given the amount of boats at Shelter Island. We will not consider any policy which would achieve the Regional Board's TMDL for Shelter Island Yacht Basin by relocating the boats elsewhere at other marinas and mooring locations in San Diego Bay, as it would simply recreate the problem elsewhere in San Diego Bay.

A different issue is whether a larger mooring area should be considered. Clearly, any type of policy that increases costs to current owners of recreational boats on San Diego Bay may cause them to consider relocating those boats elsewhere. The closest location for most of those owners would be marinas on Mission Bay. Since there is no extra capacity at Mission Bay marinas to handle a large-scale migration of boats from San Diego Bay, and to keep the scope of this project manageable, we discard the possibility of migration. It is an open question as to whether Mission Bay boats, boatyards, and marinas should be covered by any policy adopted for San Diego. There is the possibility, however, of some relocation of recreational boating activity along the California coast, as well as the likelihood that the dissolved copper problem is widespread. These should be considered when thinking about the adoption of particular policies.

A frequent response of people in the boating community was that if something was to be done about copper contamination, the same policy should be adopted throughout California or nationally. While we believe that policies targeted only at San Diego Bay can be implemented, there is clear merit in this "larger" view, the implications of which are not considered in this report.

The issue of what level of government and which specific government agency(s) should be responsible for implementing any of the policies examined is not considered in this report. The policy measures looked at in this report are feasible in the sense that it is possible to develop a practical method to do so. It is important to note, however, that in some cases enabling legislation might need to be enacted. Issues of this nature are not examined in this report.

Population of Boats

Within San Diego Bay, we consider only approximately 7,000 boats that were at slips in marinas and yacht clubs or which are at mooring locations in the month of July 2002. Thus, we exclude boats brought to San Diego Bay on trailers. Most of these boats are considerably smaller than the boats we consider and do not have copper hull coatings. This is because they are out of the water most of the time and do not need antifouling paint. There are also “partial year” boats that are in the water during the summer months but are removed in the winter. These boats are included to the extent that they were in slips or mooring locations in July 2002.

For the boats considered, we did not attempt to determine the number for which some of the alternative hull coatings would not be suitable. For instance, it is known that for some very old wooden boats with uneven hull boards many alternative hull coatings are unsuitable. There are also issues with some aluminum hull boats and very large mega-yachts that are not addressed in this report.

Adoption of a Stylized Boat

To make this report easier to understand and to help simplify the analysis in many places, we have adopted a stylized 40-foot boat with an 11-foot beam width. This is the stylized boat used by the Regional Board in their analysis. It allows one to do calculations in terms of square feet of "wet" hull (*i.e.*, 375 square feet for our stylized boat), to cast the analysis in terms of percent changes in costs from current levels, and to look at percent changes in copper leaching from current levels. It should be kept in mind that the number of square feet of hull area goes up more than proportionately with increases in boat length (and conversely goes down more than proportionately for decreases in boat length). For very large boats, the cost per square foot of hull coating application may also be somewhat higher due to the need for special equipment to handle the boat. There are differences between hull shapes for powerboats and sailboats, but these are largely ignorable for our main purposes.

Our stylized boat is repainted with traditional copper-based hull paint every two and a half years. This is the average duration between repainting for boats in our sample of boaters. Clearly for many boats the period between painting is closer to two years while for many others it is closer to three years. A much smaller number of boats are repainted more often or less often. In the former case, early repainting is sometimes required due to aggressive hull cleaning. In the latter case, delay in repainting is associated with an infrequently used boat and a heavily fouled hull. Repainting is assumed to require one coat of paint on the hull and two coats of paint on the waterline and other stress points. Clearly there are boats that only receive one coat of paint and others that receive two complete coats.

The stylized boat is assumed to need its hull paint stripped of old paint every 15 years, which corresponds to the rule of thumb of every sixth repainting. Clearly some boats go as long as 20 years before needing to be stripped while other boats are stripped much earlier due to paint or blistering problems. This estimate is important because boats that are stripped do not need to incur an added cost of conversion from copper to non-copper hull coatings.

We assume that there are approximately the same number of boats purchased new each year and that boats have a 30 year average lifespan. Clearly there are boats that are much older than 30 years, but the number of boats in recent age classes tends to be larger than those in very early age classes. For the purpose of this report, we need a straightforward estimate of the "future" number of boats that are likely to be purchased new each year and this assumption appears to produce a reasonable approximation. This estimate is important because new boats are essentially "stripped" in that any type of hull coating can initially be applied.

The combination of the 30-year lifespan and a 15 year stripping period implies that our stylized boat is currently bought new, given a coat of copper paint, stripped of old paint at 15 years, and retired from service at 30 years. We examine the sensitivity of our results to this assumption by allowing for a 40-year life span with stripping at 20 years.

We assume that our stylized boat is cleaned 14 times a year (every three weeks in the summer and otherwise monthly) by a professional hull cleaner. While this is true of many boats, there are boats that are cleaned by owners and there are boats that are very infrequently cleaned. Thus, our assumption here will overstate to some degree the amount of hull cleaning activity currently being undertaken.

Our calculations will be based upon a 7,000 boat population of 40-foot boats with a uniformly distributed age distribution over 30 years.

IV. Knowledge Needed to Evaluate Potential Policies

Several pieces of information are needed to adequately evaluate possible policy options. The first is to determine what hull coating options are available and then to classify those options in a relatively small, and hence, manageable number of types. The second is to determine cost information related to the current practice of applying traditional copper hull coatings and cost information to the application of alternative hull coatings. Here we lay out the different cost categories for hull paints and then we examine "costs" for copper and alternative hull coatings in the sense of total lifetime costs for hull maintenance.

Typology of Available Hull Coating Options

Currently available hull coating options fall into six general categories:

(1) traditional (high) copper paints with a cuprous oxide content in the 65% to 70% range,
(2) low copper paints with a cuprous oxide content in the 15% to 40% range,
(3) slick (*e.g.*, silicone) hull coatings,
(4) hard smooth epoxy hull coatings,
(5) epoxy and fibers hull coatings, and
(6) epoxy with suspended copper flakes hull coatings.

Generally one can paint over the current traditional copper paints with another coat of either traditional copper paint or low copper paint with only standard sanding and preparation work. Application of the other types of hull coatings generally requires that the boat be stripped of the old copper paint first. Paint type (5) was not successful in the demonstration project that is being conducted simultaneously with this project, and hence, has been dropped from further consideration. Additionally, we have been unable to evaluate the last type of hull coating (6) since it has not been included in the demonstration project and because it not currently licensed for use in California, although it is registered by U.S. EPA and available elsewhere.

Cost Categories: Traditional Copper and Alternative Hull Coatings

To evaluate policy options one needs to know the current cost to boat owners of the traditional copper hull paints, including cleaning practices currently in use. Second, one needs to know similar information for each of the alternative paints considered. This information is provided in Appendix D2 and D3 in the form of:

(a) repainting cost [including paint costs] per square foot for our stylized 40 foot boat,
(b) duration between the repainting time,
(c) how often a boat needs to be stripped of old paint and the cost of stripping if needed,
(d) cost per square foot for cleaning the hull, and
(e) annual frequency of hull cleaning required.

For traditional copper paints, the two paints we consider are Proline 1088 and Interlux Ultra Kote. These are among the most frequently used by San Diego boatyards and boaters are often offered a choice between the two at no cost difference. The application of such traditional copper paints is the “baseline” against which alternatives are to be compared. We have assumed a cost of $30 per foot for a standard paint job, which includes a haul out, basic hull preparation, paint, and labor. Small changes in this $30 cost have little influence on evaluating the policy options as it is typically the relative costs of traditional copper paint and the alternative hull coating which is relevant.

Most low copper paints do not meet San Diego VOC requirements. We look only at ones that do meet these requirements. The low copper paints fall into two categories: non-ablative paints, where we look at Interlux Fiberglass, BottomKote Aqua, and Pettit Unepoxy, and ablative paints (which are self cleaning)[2], for which we look at Flexdel Aquaguard and Z Spar Hydrocoat Extra. Application of low copper paints is similar to that of traditional copper paints, except perhaps for the actual cost of the paint.

For the two silicone based paints we considered ProTect Water Shield (also known as Miracle Cover) and Interlux Veridian, which have received some limited local application in San Diego. Miracle Cover is currently being evaluated in the course of the demonstration project. For the epoxy type paints, we look at AquaPly-M and CeRamKote-54, which are also being used in the demonstration project. Silicone paints have been shown to have small fuel efficiency and speed advantages over copper paints, while there is some belief that epoxy paints have small disadvantages in fuel/speed relative to copper paints. The implications of this issue are not considered in this report.

For both of these types of non-toxic paints (silicone and epoxy), there are key uncertainties involved with respect to application cost. These uncertainties take two forms. First, the labor cost must be considered. The uncertainties here follow from the belief that the non-toxic paints can be more difficult to apply. The second consideration is paint cost. There is a fair amount of variability in paint prices. For instance, Veridian is one of the most expensive paints considered, while Miracle Cover is one of the least expensive. The paint prices of the non-toxics are also more variable than prices of traditional copper paints, but their prices are likely to both fall and stabilize over time if

[2] Currently the only ablative paints being commercially used are copper based, although silicone has some similar self-cleaning properties at high speeds. An ablative non-toxic paint could substantially reduce one

they become more widely used on recreational boats. We therefore assume a cost range of $30 to $50 for the application of non-toxic paints. The $30 represents the same price as copper, while the $50 is 66% higher than the price of copper. We use $40 as our best estimate of price of non-toxics over the longer run, which implies that non-toxics are 33% more expensive to apply than copper paints.

A key uncertainty includes the duration between repainting for the alternative paints. In this regard, four years seems like a lower-bound estimate; and there are loose claims by some epoxy type paint manufacturers of a ten-year plus life span. We use 7. 5 years as our best estimate. The first boat in San Diego Bay painted with epoxy was done almost four years ago. Recent inspection of that boat during the current demonstration project revealed that the hull paint showed almost no wear, which provides some support for a ten-year lifespan claim.

Another uncertainty concerns the optimal hull cleaning frequency for the different hull coatings being considered. It is clear that the need for hull cleaning is dependent upon several factors including temperature, nutrients, frequency of boat use, and speed of boat use. Generally, hull coating alternatives to traditional copper appear to require more frequent cleaning. The necessary cleaning frequency for a hull painted with an alternative paint seems to range. The low end of this range is roughly every three weeks (which is quite similar to copper paint's summer cleaning frequency), and the high end of the range is weekly cleaning. Paints that lie in this high end include epoxy and silicone paint, if it is on a boat that is infrequently used.

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of the main extra costs of non-toxic paints: more frequent cleaning. Such a possibility is not explored in this report.

Hull Maintenance Cost: A Total Lifetime Cost Perspective

A comparison between traditional copper-based hull paints and a non-toxic alternative (like an epoxy hull paint) will almost always show that the copper-based hull paint has lower initial costs. This cost advantage becomes even larger if one considers costs over the first couple of years. This is because it is currently less expensive to paint a boat with traditional copper paints and maintenance is also less because a boat painted with traditional copper paint needs to have its hull cleaned less often.

However, taking a longer perspective can reverse this conclusion. The main reason for this is that an epoxy hull coat lasts considerably longer: 5 to 10 years versus 2.5 years for copper. Thus, a hull painted with epoxy paint will need to be repainted anywhere from half to a quarter as often. This repainting cost should be balanced against the higher initial painting costs and the higher hull cleaning costs over the course of the life of the epoxy hull paint.

There is one additional cost that looms large in considering traditional copper versus a non-toxic paint like epoxy and that is whether the boat needs to be stripped of the old copper paint before the non-toxic paint can be applied. This is generally the case because stripping costs tend to be much larger than the painting costs (*e.g.*, $150 per foot of boat length for stripping old paint and applying new paint versus $30 per foot of boat length for applying traditional copper paint on our stylized 40-foot boat), a comparison of total lifetime costs depends critically on whether the boat has to be stripped in order to apply the non-toxic hull coating.

There is one situation where stripping is not required in order to apply a non-toxic paint and that is with a new boat. A new boat comes with a “gel coat” and one can apply either traditional copper to it or most non-toxic paints without additional preparation.

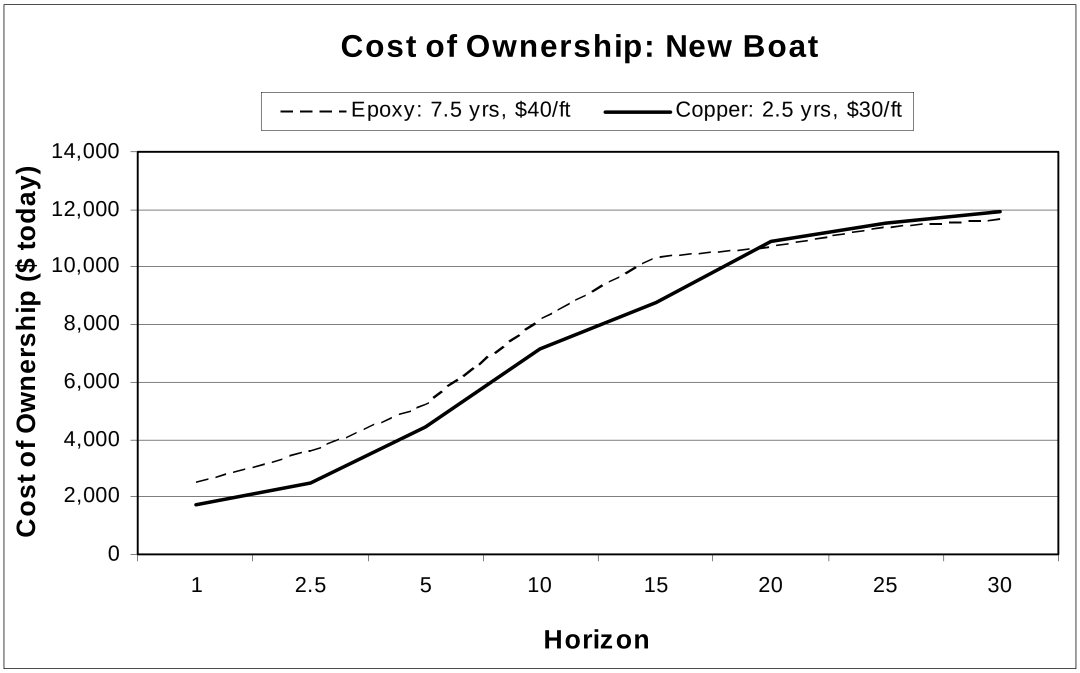
There is also one situation when both copper and non-toxic paints face identical stripping costs and that is with an older boat for which the build-up of old copper paint is such that it must be stripped off before either copper or a non-toxic paint will correctly adhere. More generally, the closer an existing boat with copper paint is to needing to be stripped, the more favorable the cost comparison between copper and the non-toxic will be. In this sense, a new or newly stripped hull can be seen as an asset that depreciates over time, each time it is repainted.

We assume that a boat’s hull must be stripped after each 6th repainting. Thus, with copper-hull paint that lasts 2.5 years, a boat will need to be stripped at 15 years. For epoxy, the boat will never need to be stripped because with a paint duration of 5 years, the 6th repainting would be at the boat’s retirement at 30 years of age and at a paint duration of 10 years means that it would have only been painted 3 times.

Balancing costs occurring in different time periods requires a discount/interest rate. We consider three real discount rates. (A real discount rate is one which is not adjusted for inflation.) The first of these is 0%. With this discount rate, costs are counted the same no matter what period they occur in. The second is 5%. This is equal or above the rate of return over the last five years on most investment assets and represents what might be thought of as an alternative for investing now to reduce hull maintenance costs later. The third interest rate is 10%. This rate is about what many good credit risk people are paying as the interest rate on their credit card balances. This rate represents the opportunity cost of borrowing money to invest in hull maintenance. Different people may view policies with the same costs but occurring in different time periods differently, due to the discount rate they perceive they face with respect to hull maintenance decisions. In the rest of this section we will use a 5% discount rate. Tables that compare total lifetime costs with all three discount rates appear in Appendix D.

Total lifetime costs for a new 40-foot boat are shown in the figure below that assumes copper costs $30 per square foot and epoxy $40 per square foot. The copper boat is assumed to need to be cleaned 14 times per year and the epoxy boat 22 times. The cost of each cleaning is assumed to be $40 ($1 per linear foot). The duration between repainting is 2.5 years for copper and 7.5 years for epoxy (halfway between in our 5 to 10 year range). The copper boat needs to be stripped once at 15 years. A 5% discount rate is assumed. What can be clearly seen here is that using copper is less expensive to begin with but that this cost advantage falls as one considers total lifetime cost over longer time horizons. Epoxy becomes the less expensive alternative at a time horizon of 18 years or longer. The other thing to note is that for time horizons of 5 years or beyond, the total lifetime cost profiles of copper and epoxy are fairly close.

FIGURE 1



The next figure shows the total cost of hull maintenance for our stylized boat for copper and epoxy under four different conditions which are combinations of epoxy paint prices (*i.e.*, the current $50 per square foot price and falling to the current $30 copper price) and repainting durations (*i.e.*, 5 years the lower bound on our range and 10 years the upper bound on our range). What is noteworthy is that only in the case where epoxy has to be painted every 5 years (and the price of epoxy doesn't decline from its present $50) does copper have a lifetime cost advantage. In this case, the cost advantage of copper over the 30 year period is almost $1500, so hull maintenance costs with epoxy are 12% higher. All of the other three conditions favor epoxy. For the 10 year duration and $30 paint cost, epoxy is less expensive by just over $1500 and dominates copper when time horizons of ten years or more are considered. For the two other combinations, epoxy is a few hundred dollars less expensive than copper, and it dominates copper when time horizons of 20 or more years are considered.

FIGURE 2

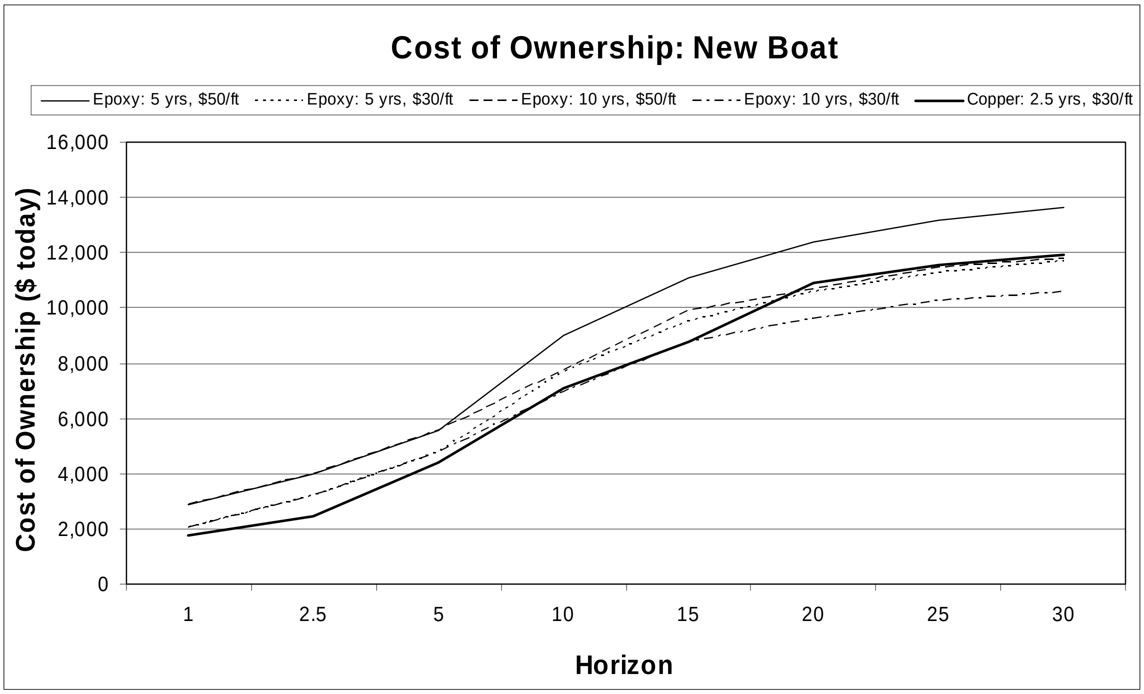


Table 1 shows the estimates for a new boat under different epoxy paint duration, epoxy paint costs and discount rate combinations. Since we have discussed the general implications of the first two assumptions it is useful to concentrate here on the discount rate. Comparing similar paint duration and cost conditions, one can observe that the (discounted) 30 year cost estimates fall as the discount rate increases and epoxy becomes less attractive relative to copper as discount rate increases. This latter phenomenon occurs because the "benefits" of epoxy relative to copper (not having to repaint as often) occur in later time periods while the cost of copper (having eventually to strip the old paint off the boat once it gets too many coats) occurs in a much later period.

Table 1: 30 Year Cost of Ownership: New Boat
Cost of Cu = 30$/ft
Cu hull cleaned 14 times/year; Epoxy hull cleaned 22 times/year

Discount Rate	Epoxy Paint Reapplication	Cost of Epoxy ($/ft)	30 Year Cost of Ownership: Copper Hull	30 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
0%	Every 5 Years	50	36,000	38,400	2,400
0%	Every 5 Years	30	36,000	33,600	-2,400
0%	Every 10 Years	50	36,000	32,400	-3,600
0%	Every 10 Years	30	36,000	30,000	-6,000
5%	Every 5 Years	50	11,922	13,648	1,726
5%	Every 5 Years	30	11,922	11,687	-235
5%	Every 10 Years	50	11,922	11,783	-139
5%	Every 10 Years	30	11,922	10,568	-1,354
10%	Every 5 Years	50	6,500	8,068	1,568
10%	Every 5 Years	30	6,500	6,771	270
10%	Every 10 Years	50	6,500	7,166	665
10%	Every 10 Years	30	6,500	6,229	-271

A boat stripped today (Table 2) produces an identical epoxy minus copper difference for a thirty year cost of ownership as that in Table 1, although the 30 year cost of ownership is substantially higher for the boat in Table 2 than for a new boat due to the need to pay the stripping cost.

Table 2: 30 Year Cost of Ownership: Boat Stripped Today
Cost of Cu = 30$/ft
Cu hull cleaned 14 times/year; Epoxy hull cleaned 22 times/year

Discount Rate	Epoxy Paint Reapplication	Cost of Epoxy ($/ft)	30 Year Cost of Ownership: Copper Hull	30 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
0%	Every 5 Years	50	40,800	43,200	2,400
0%	Every 5 Years	30	40,800	38,400	-2,400
0%	Every 10 Years	50	40,800	37,200	-3,600
0%	Every 10 Years	30	40,800	34,800	-6,000
5%	Every 5 Years	50	16,722	18,448	1,726
5%	Every 5 Years	30	16,722	16,487	-235
5%	Every 10 Years	50	16,722	16,583	-139
5%	Every 10 Years	30	16,722	15,368	-1,354
10%	Every 5 Years	50	11,300	12,868	1,568
10%	Every 5 Years	30	11,300	11,571	270
10%	Every 10 Years	50	11,300	11,966	665
10%	Every 10 Years	30	11,300	11,029	-271

It might be more reasonable here to consider a 15 year cost of ownership because, if our stylized boat is being stripped today on its normal schedule, it only has a 15 year service life left. Table 3 displays these results. What is useful to note here is that the case for non-toxic paints is less favorable and the effect of the discount rate is less clear because of the need to repaint epoxy but not to strip the old copper off again. Epoxy is only favored over copper from a lifetime cost perspective at our standard 5% discount rate in the optimistic case that application of epoxy paint falls to the copper price of $30 and epoxy hull paint lasts 10 years. The advantage for epoxy is only $26 out of a total hull maintenance cost for copper of $13,580, which is hardly enough to get boaters who only care about cost (or prefer copper) to flock to epoxy. In the pessimistic case with a 5% discount rate, an epoxy cost of $50 a square foot and a paint duration of 5 years, epoxy costs $2,303 more than copper which is just under a 17% premium. This translates into an extra cost of about $150 more per year for the 15 year remaining life of this boat. Neither the trivial upside cost advantage of $1.50 a year under optimistic conditions nor the downside advantage of $150 per year under the most pessimistic assumptions is likely to have a large impact on boaters. Such cost numbers, however, are hardly those that would get boaters who only care about cost (or prefer copper) to flock to epoxy.

<u>Table 3: 15 Year Cost of Ownership: Boat Stripped Today</u>
Cost of Cu = 30$/ft
Cu hull cleaned 14 times/year; Epoxy hull cleaned 22 times/year

Discount Rate	Epoxy Paint Reapplication	Cost of Epoxy ($/ft)	30 Year Cost of Ownership: Copper Hull	30 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
0%	Every 5 Years	50	20,400	24,000	3,600
0%	Every 5 Years	30	20,400	21,600	1,200
0%	Every 10 Years	50	20,400	22,000	1,600
0%	Every 10 Years	30	20,400	20,400	0
5%	Every 5 Years	50	13,580	15,884	2,303
5%	Every 5 Years	30	13,580	14,291	711
5%	Every 10 Years	50	13,580	14,656	1,076
5%	Every 10 Years	30	13,580	13,554	-26
10%	Every 5 Years	50	10,688	12,431	1,743
10%	Every 5 Years	30	10,688	11,204	516
10%	Every 10 Years	50	10,688	11,660	972
10%	Every 10 Years	30	10,688	10,741	53

An interesting difference appears if we look at boats that were first painted 2.5 years ago, that is they are coming up for their first time to be repainted with copper. We look at the 30 year lifetime costs to facilitate comparison with our earlier examination of new boats, although looking at a 27.5 year lifetime cost in Table 4 shows a very similar pattern of results. What should be noted here is that copper is favored in all cases except one; in this case both the unrealistic 0% discount rate is used (where boaters do not care what year expenses are incurred), and we make favorable epoxy cost and duration assumptions. Furthermore, at our standard 5% discount rate, the cost disadvantage of epoxy runs from 30% to 50%. This is a substantial obstacle to overcome because the cost differential is now sizeable.

Table 4: 30 Year Cost of Ownership: Boat Stripped 2.5 Years Ago
Cost of Cu = 30$/ft
Cu hull cleaned 14 times/year; Epoxy hull cleaned 22 times/year

Discount Rate	Epoxy Paint Reapplication	Cost of Epoxy ($/ft)	30 Year Cost of Ownership: Copper Hull	30 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
0%	Every 5 Years	50	40,800	43,200	2,400
0%	Every 5 Years	30	40,800	38,400	-2,400
0%	Every 10 Years	50	40,800	37,200	-3,600
0%	Every 10 Years	30	40,800	34,800	-6,000
5%	Every 5 Years	50	12,557	18,448	5,891
5%	Every 5 Years	30	12,557	16,487	3,930
5%	Every 10 Years	50	12,557	16,583	4,026
5%	Every 10 Years	30	12,557	15,368	2,811
10%	Every 5 Years	50	6,693	12,868	6,175
10%	Every 5 Years	30	6,693	11,571	4,877
10%	Every 10 Years	50	6,693	11,966	5,272
10%	Every 10 Years	30	6,693	11,029	4,336

We now look at a boat that was stripped 12.5 years ago. Here we provide two tables: One (Table 5) gives the 30 year lifetime cost of ownership to facilitate comparison with earlier tables and one (Table 6) gives a 17.5 year lifetime cost of ownership because this is the assumed service life the boat has left. This second table is best compared to the 15 year lifetime cost of ownership table, provided earlier for a boat that has just been stripped. For the 30 year table, note that the cost comparison between copper and epoxy is much more favorable to epoxy. Instead of having a cost disadvantage of 50% to 30% with a 5% discount rate, one is now looking at a cost disadvantage of 20% to being very slightly favorable to epoxy. This suggests that boats that will soon need to be stripped are much better candidates from a cost perspective for conversion to non-toxic hull paints than are boats that are close to new or only recently stripped.

Table 5: 30 Year Cost of Ownership: Boat Stripped 12.5 Years Ago
Cost of Cu = 30$/ft
Cu hull cleaned 14 times/year; Epoxy hull cleaned 22 times/year

Discount Rate	Epoxy Paint Reapplication	Cost of Epoxy ($/ft)	30 Year Cost of Ownership: Copper Hull	30 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
0%	Every 5 Years	50	40,800	43,200	2,400
0%	Every 5 Years	30	40,800	38,400	-2,400
0%	Every 10 Years	50	40,800	37,200	-3,600
0%	Every 10 Years	30	40,800	34,800	-6,000
5%	Every 5 Years	50	15,443	18,448	3,005
5%	Every 5 Years	30	15,443	16,487	1,044
5%	Every 10 Years	50	15,443	16,583	1,140
5%	Every 10 Years	30	15,443	15,368	-75
10%	Every 5 Years	50	9,376	12,868	3,492
10%	Every 5 Years	30	9,376	11,571	2,194
10%	Every 10 Years	50	9,376	11,966	2,589
10%	Every 10 Years	30	9,376	11,029	1,653

Looking at the 17.5 year lifetime costs of hull maintenance in Table 6 provides an even more optimistic picture for epoxy. Here with the 5% discount rate, copper is favored at the pessimistic cost and duration assumptions for epoxy. Indeed, the estimate here is even slightly more favorable than that for Table 3, which was a 15 year service life table for boats just being stripped. The reasons for this small advantage have to do with the expected duration of the epoxy paint and the timing of the stripping. This illustrates the point that it is hard to predict for which boats the epoxy-copper cost difference is most favorable to epoxy, except that they will be boats that either need or are close to needing to be stripped.

Table 6: 17.5 Year Cost of Ownership: New Boat
Cost of Cu = 30$/ft
Cu hull cleaned 14 times/year; Epoxy hull cleaned 22 times/year

Discount Rate	Epoxy Paint Reapplication	Cost of Epoxy ($/ft)	17.5 Year Cost of Ownership: Copper Hull	17.5 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
0%	Every 5 Years	50	23,000	23,400	400
0%	Every 5 Years	30	23,000	20,200	-2,800
0%	Every 10 Years	50	23,000	19,400	-3,600
0%	Every 10 Years	30	23,000	17,800	-5,200
5%	Every 5 Years	50	10,463	12,009	1,546
5%	Every 5 Years	30	10,463	10,231	-232
5%	Every 10 Years	50	10,463	10,319	-144
5%	Every 10 Years	30	10,463	9,217	-1,246
10%	Every 5 Years	50	6,298	7,851	1,552
10%	Every 5 Years	30	6,298	6,578	279
10%	Every 10 Years	50	6,298	6,965	667
10%	Every 10 Years	30	6,298	6,046	-252

Appendix D includes a number of additional tables on costs of ownership for boats in different situations. The first set of these tables looks at the number of years since the boat was first painted. This set of tables reinforces the finding from the tables presented in this section that the low cost candidates for epoxy hull paints are the new boats that have not yet had copper applied, and the boats that either currently need to be stripped or that will soon need to be stripped. The next set of tables in this appendix looks at the sensitivity of the results to copper and epoxy paint cost, cleaning frequency, and stripping cost, as there is still considerable uncertainty about many of these factors, particularly regarding different non-toxic paints. There are two lessons here. The first is that epoxy paints are usually fairly competitive unless the factors that favor them go in the "wrong" direction. In addition, dropping the price of copper paint, but maintaining the overall price differential between copper and epoxy paint, makes epoxy look somewhat less attractive. The second lesson is that there is considerable upside gain for boaters if most of the factors influencing total lifetime costs for non-toxics go in a favorable direction. Using the low end of the range for stripping costs tends to make very little difference. Making copper last 15 years vs. 10 years makes epoxy look better, but the effects of this are not extremely large. The largest effect is observed when we decrease the frequency of copper cleaning to 10 times per year, which is consistent with the average in our survey, and increase the frequency of cleaning of epoxy to 26 times per year, which is consistent only with the recommendations of paint manufacturers for silicone paints. However, cleaning epoxy 22 times per year, as in our baseline scenario, is consistent with the recommendations of underwater hull cleaners. The last table in this appendix looks at new boats with a longer (35 and 40 year) lifetimes and longer (17.5 year and 20 year) stripping durations. The results here are reasonably close to that for a new boat with a 30 year life. That is in part because the concept of needing to be stripped one time has been maintained and because the time period of 30 to 40 years in the future is being fairly heavily discounted with the use of any reasonable discount rate.

Influence of Different Hull Cleaning Practices

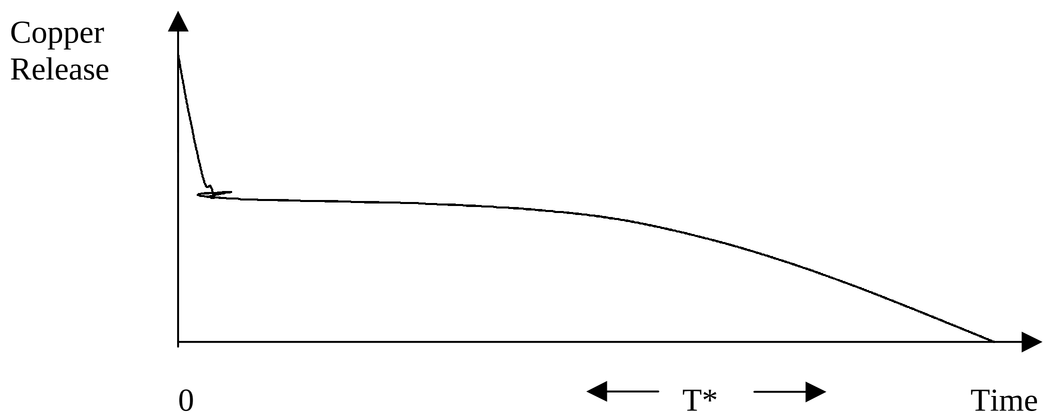
The draft technical TMDL for dissolved copper in Shelter Island Yacht Basin calls for a 66% reduction in copper coming from in-water hull cleaning, as well as a 66% reduction in copper coming from passive leaching of hull paints. In order to determine how this requirement for in-water hull cleaning might best be achieved, two types of information are required. First, a baseline is needed. Formally, this should be the "excess" copper being released as a result of a hull cleaning for our stylized 40-foot boat averaged over current copper paints and hull cleaning practices. Second, the influence of different hull cleaning practices on "excess" copper releases needs to be known. Unfortunately, neither of these two types of information is available.

With respect to baseline data, the one study to date which attempts to quantify the concentration of chemicals released by underwater hull cleaning in San Diego was prepared in 1995 by McPherson and Peters for the Regional Water Quality Control Board. However, the report does not specify the type of copper paint used in the test, although from the discussion at the end of the report (p. 41) it appears that ablative paints were studied. This is consistent with the beliefs of several San Diego hull cleaners. Ablative copper paints are infrequently used on boats in San Diego Bay, and, more importantly, they are designed not be cleaned but rather to slough off a very thin layer of copper along with the accumulated fouling when the boat moves at high enough speeds through the water. Cleaning an ablative paint is likely to result in a much higher immediate copper release than cleaning standard copper paint.

Another difficulty with this study is that it looks at the amount of copper coming off a boat during one cleaning. San Diego Bay contains a large number of recreational boats in a relatively small space, all in different phases of their hull-painting schedule. As such, the relevant numbers are the length of the period between when a boat is first painted and when it is repainted with copper paint, and the amount of copper coming off a boat during this time period. Active loss during hull cleaning and passive loss through leaching both contribute to this release. The key question is what does the lifetime profile of copper loss from boats look like and how is it influenced by various hull cleaning practices?

Though studies which accurately assess leaching rates are limited, it is widely agreed that a surface coated with traditional copper leaching paints (or “hard paints”) that is not being cleaned has a comparatively high copper release rate immediately following paint application. Next, the rate of copper release stabilizes for a relatively long time period and then enters a stage where it declines slowly. Eventually, the coat of copper paint wears off. This lifecycle of copper release following paint application can be characterized by Figure 3, where the hull is painted at time 0 and it is optimal to repaint the hull at T*.

FIGURE 3: COPPER RELEASE FOLLOWING PAINT APPLICATION



Various factors can shift T* to the left or right, signifying shorter and longer optimal paint lives, respectively. Through discussions with boat cleaners, boatyards, and recreational boaters in San Diego Bay, it is clear that a "bad" underwater hull cleaner can abuse the antifouling paint and thereby shorten the life of the paint, whereas a "good" diver can prolong its life. Examples of abusive practices are the use of overly abrasive cleaning materials and overly aggressive cleaning.

The crucial insight to this analysis is as follows: the amount of copper released during any single cleaning is the wrong measure of "excess" copper loss due to cleaning. The correct measure is the change in how long a hull paint lasts under different hull cleaning practices. The amount of time that a paint's life can be prolonged by good cleaning practices is unknown since no direct study of this issue exists. One year, however, appears to be a conservative estimate of the difference between the life of a properly cleaned hull's paint and a poorly cleaned hull's paint. If this is thought of in terms of the difference between having to repaint at 2 years versus 3 years, then policy measures that institute good hull cleaning practices and eliminate bad hull cleaning practices can result in a 33% reduction in copper from recreational boats.

In addition to maintenance related factors, economic factors such as the price of copper paint can affect T*. An increase in the price of copper paint would delay the time at which it is optimal for a boater to apply a new coat of paint, and therefore, would shift T* to the right. There are claims that the life of a standard coat of copper paint can be extended to 4 to 6 years by substituting labor in the form of very frequent hull cleanings.

For underwater hull cleaning practices to be improved upon with the objective of shifting T* to the right (extending the life of the paint), explicit tests must be conducted. The effects of alternative cleaning practices on the antifouling paint's lifecycle must be understood for any such recommendation to be made. It is possible that either mandating what are now considered hull cleaning best practices or requiring an alternative procedure identified during a formal testing process could play an important role over short to moderate term horizons in reducing copper from recreational boats in San Diego Bay.

Boatyard Conversion Capacity

In considering policies to move from traditional copper paints to alternatives, one of the first questions that should be asked is, "What are the practical constraints in making the change?" If alternative paints are available, this question takes the form, "What is the physical capacity of boatyards to make the change?"

Constraints on boatyard capacity make achieving a quick conversion from copper hulled boats to boats with non-toxic hull paints impossible. To see the reason for this, first note that San Diego Bay boatyards serve a stable population of boats and are operating at close to full capacity. Then ask the question, “Does it take more time to convert a boat to non-toxics than it does to repaint it with copper-based hull paints?” The answer here is “Yes.” Extra time is required due to the need to take off all the old paint (which is not generally necessary for boats with copper hulls) and much more extensive hull preparation work. Effectively what is needed is to completely strip the hull. This operation is now performed routinely at San Diego boatyards for boats that have so many layers of old copper paint built up that it must all be stripped off in order to apply the new coat correctly. Depending upon the boatyard, the time to convert a boat (strip it and then apply non-toxic paints) is anywhere from 80% to 133% longer. The range of extra time costs seems driven by factors internal to particular boatyards such as equipment, room for boats, and the nature of hull preparation work done for repainting copper hulls. Most of the time, costs are associated with the need to strip the boat and not the application of the non-toxic paint. Further, we expect that the extra amount of time some boatyards believe that application of non-toxic paints requires will fall to closer to that required by copper paints as more experience applying non-toxic paints is gained. As such we will assume that converting a current boat with copper paint to non-toxics will require twice as much time by boatyards.

Boatyards currently have the capacity to maintain the copper paint on all boats in San Diego Bay. It is important to note that there are two situations in which no additional boatyard capacity is needed to convert boats to non-toxic hull coatings. The first of these is when painting the hull of a new boat, since there is no “old” paint to take off. The second is with a copper boat that already needs to be stripped. Since alternative hull coatings appear to need to be repainted less often, this frees up boatyard capacity to be used for conversions over time.

We also assume that boatyards could increase the amount of capacity devoted to recreational boat hull coating maintenance by 10%. An ability to increase capacity through reorganization of work, hiring additional staff, and obtaining additional equipment is standard in most industries. The ability to store boats on location coupled with the need for the paint applied to boats to adequately dry suggest that very large increases in capacity are unlikely. There is a further problem with respect to the purchase of new equipment: in the short term there will be more hull maintenance work but in the long run the use of non-toxic hull coatings implies less hull maintenance work by boatyards. This provides a strong incentive against large capital expenditures that would substantially increase long-term hull maintenance capacity.

Boatyard Experience with Alternative Hull Coatings

San Diego boatyards have limited experience with non-toxic hull coatings; some boatyards have almost no experience and others have applied non-toxic hull coatings to over several dozen boats. The experience to date suggests that some non-toxic hull coatings can be applied, but that the knowledge necessary to undertake large scale commercial conversions of several hundred to several thousand copper hull boats per year is lacking. This is because the physical application of non-toxic paints is fundamentally different than copper-based paints. There are also problems related to the poor physical appearance of some of the non-toxic paints once applied to hulls in spite of test panels that looked good. A poor physical appearance will make non-toxic hulls unpopular with many boaters who put considerable weight on having a sleek, good looking, and well maintained boat.

Both the application and physical appearance problems can be solved by moving from a "proof of concept" demonstration project to a larger scale demonstration project with the objective of developing techniques for efficient commercial application. Such a demonstration program will reduce later application costs for non-toxic paints, and hence, will further their adoption by boaters.

There is another aspect of greater commercial experience that is important. Boatyards effectively warranty the hull coatings they apply against problems. The experience to date with the application of non-toxic hull coatings has not been uniformly positive. It has been necessary to remove or replace hull coatings in several instances.

The usual solution to such problems with "new" products by retailers is for the manufacturer to provide guarantees or warranties against such problems, and thereby, pay to correct problems if they occur. Non-toxic hull paint manufacturers appear unwilling to do this for several reasons. First, many companies with current or proposed non-toxic hull paints are small and lack the financial resources to provide guarantees or warranties on a large scale. Second, some of the non-toxic paints were developed for applications other than marine recreational boats, and hence, the manufacturer lacks experience in this area. Finally, there are persistent disagreements between boatyards and paint manufacturers on how particular paints should be applied. This seems to be due to a lack of large-scale application experience and a divergence between "test lab" conditions and application outdoors on actual boats. Paint manufactures are naturally reluctant to provide guarantees against failure when they don't have control over how their product is applied. The most paint manufacturers appear willing to do is to provide replacement paint when they believe their product was at fault. However, labor costs are substantially larger than the paint costs, leaving the boatyard with considerable exposure. To cover the risk of applying non-toxic paints, rational boatyards will charge a premium. This premium is likely to fall as boatyards gain more experience and learn how to successfully apply particular products.

Whether the demonstration project should be funded at the local, state, or federal level or cooperatively is an important implementation issue that is not considered here. Without such a demonstration project, sufficient capacity to achieve the copper reduction objectives may be lacking and higher costs of applying non-toxic paints will drive up the overall cost of the program.

Safety Inspections and Other Repair Work

Boat owners often have safety inspections and needed repair work (*e.g.*, replacing zincs) done on their boats when they are hauled out for a routine application of new copper hull paint. The reason this is done is that there is a fixed cost associated with hauling a boat out (*e.g.*, approximately $320 for our stylized 40-foot boat) that is built into the cost of repainting a hull. Thus, a haul out fee is avoided if other work is done at the same time as the boat's hull is repainted. Indeed, only 16% of our sample of boaters had found it necessary to have their boats hauled out for maintenance between hull repaintings. Further, with the boat out of the water, experienced boatyard personnel are in a position to bring a variety of safety related issues to the attention of a boat owner.

A shift to non-toxic paints will imply that boats are hauled out less often for repainting. This has the implication of increasing repair costs to the extent that the boat is specifically hauled out for that purpose and decreasing boat safety to the extent that safety related issues that were observed and corrected while the boat was being repainted are now missed.

Policies that might be adopted if the safety issue is judged to be a significant one include routine haul out for safety inspections, particularly with respect to any metal that is underwater, and to determine how well paint is holding up. Special training for hull cleaners might be needed on how to recognize potential safety issues that require attention.

Boater Knowledge and Preferences

A survey was conducted to assess boaters' knowledge about copper hull paints and non-toxic alternatives and their preferences toward various hull painting options. The group of recreational boaters surveyed were drawn from a stratified random sample of boats at marinas and mooring locations in San Diego Bay. The survey sampling plan is contained in Appendix F1, the survey instrument used in F2, and data tabulations in F3.

A brief description of the sample characteristics is as follows: Ninety percent of our sample owned one boat in San Diego Bay with ten percent owning two or more. The mean boat length was 36 feet with a range of 18 feet to 114 feet in length. Eighty percent of the boats were between 25 and 45 feet in length. Fifty-nine percent of the boats were sailboats. The average age of a boat was 21 years with the oldest boat being built in 1930 and the newest boat being built in 2001. Eighty percent of the boats were built between 1969 and 1997. The average number of years the boat had been owned was 7 years. Owners were mostly male, with an average age of 54, generally well educated, and mostly had upper middle class income levels. Boats were heavily used in the summer with 30% of those surveyed sailing more than once a week, 22% once a week, 30% two or three times a month, 10% once a month, and 8% less than once a month. Sailing fell off somewhat in the spring (21% more than once a week, 15% once a week, 30% two or three times a month, 24% once a month, and 10% less than once a month) and in the fall (20%, 15%, 34%, 19%, and 12%, respectively) and then dropped even more in the winter (18%, 11%, 24%, 24%, and 23%).

The average boat was repainted every 31 months with most boat owners using copper based hull paint (or not knowing what paint was being used), although 3% of those surveyed reported using epoxy. Twenty-two percent of the boaters had at some time had their boats hauled for maintenance between repaintings.

Most survey participants (63%) knew that the Regional Water Quality Control Board had found that there was a pollution problem involving copper in San Diego Bay. Of those with this knowledge, most were not aware that the Regional Water Quality Control Board had found that recreational boats were the source of the problem. However, many of these boaters were aware that copper was toxic to marine organisms. Less than half of these respondents were aware that the Regional Water Quality Control Board was legally required to reduce the copper pollution to ensure that water quality standards were no longer violated in San Diego Bay. Taken together, these findings suggest that, while there is a group of reasonably well-informed boaters, many are not. Perhaps the most telling from the perspective of this report is that 80% of the boaters interviewed were not familiar with any specific non-toxic bottom paints.

The boaters were then asked a series of nine questions that took the form of a 5 point scale (not important, slightly important, somewhat important, very important, and extremely important). On the first question 21% indicated that old copper paint being expensive to remove was an extremely important factor in deciding whether to switch to a non-toxic bottom paint, while 18% found this to be a very important factor, 32% a somewhat important factor, 14% a slightly important factor and 15% not to be an important factor.

Non-toxic paint lasting longer clearly mattered significantly to boaters, with 40% rating this as an extremely important factor and another 37% as a very important factor. This suggests that the duration that the non-toxic paint lasts will be an important factor in boaters' decisions concerning whether or not to switch to non-toxic paints. Having to clean the hull more often was also a factor (25% extremely important and 31% very important), but does not appear to weigh in as significantly as paint duration.

Ratings of a recommendation to switch by a boatyard (12% extremely important and 27% very important) or by an underwater hull cleaner (13% extremely important and 26% very important) show that these two providers of boat maintenance services have some influence over boaters' decisions. However, these recommendations would pale in comparison to the effect of non-toxic paint being required by the marina, yacht club or mooring location (31% extremely important, 31% very important), and the effect is even more significant if the switch is required by law (50% extremely important, 26% very important).

Also having some impact was the possibility that the boat might be easier to resell if painted with non-toxic bottom paint, which 20% of the boater sample found to be extremely important and another 25% found very important. A perception that non-toxic bottom paint would help make San Diego Bay cleaner was also a factor for some boaters, with 33% rating this as an extremely important factor in switching and 37% rating it a very important factor in switching.

Modeling Boater Hull Coating Choice

In the second half of the survey, subjects were asked a series of questions in which they had to choose their most favorite and least favorite paints out of sets of four paints. The paint choices that they could decide between had five attributes that varied across the different paint choices: paint type, one-time hull conversion cost, paint application cost, required painting frequency, and required cleaning frequency. (See Appendix F for specific attribute levels.) Using econometric methods to construct a choice model, we were then able to quantify various preferences and expected behavior of the boating population.

Two general points stand out from the responses in this section, and should be noted before specific model results are presented. The first is that there are clearly different types of boaters with respect to their preferences for hull paints. There is a group that is willing to switch to non-toxics even if they are substantially more expensive than copper, a group that is roughly indifferent between non-toxics and copper at similar prices and performance characteristics, and a group that favors copper even if it is more costly than non-toxic hull coatings. The middle group is the largest one. The presence of the first group suggests that an educational campaign covering the environmental attributes of the non-toxic paints and their cost/performance characteristics might persuade some boaters to switch. The presence of the third group suggests that voluntary measures alone will not be successful in phasing out the use of copper paints, even if non-toxic hull paints are shown to have (small) advantages with respect to price and performance.

The second point is that implementing a date by which boats with copper hull coatings will be banned substantially altered the paint choices that boaters reported. Our survey made use of a split sample design whereby half of those surveyed were given the following statement before the series of choice questions: "It is very likely that ten years from now all recreational boats in San Diego Bay will be required to be painted with a non-toxic paint." The other half of the sample was not given this statement. (However, the information in this statement might have been reasonably inferred by some respondents from earlier information in the survey about the legal requirement of the Regional Water Quality Control Board to reduce copper pollution. Hence the statement's true impact may be larger than reported here). The half of the sample not receiving the statement that non-toxics would be required in 10 years were on average 33% more likely to indicate that they would pick copper the next time their boat was repainted than those receiving the statement. This suggests that setting a future date by which copper is banned can have a powerful influence on current hull paint choices.

Next, the choice model was analyzed in order to answer some specific questions regarding boaters' preferences. The following properties of boaters' choices were found:

(1) Boaters are willing to pay about $700 in order to put off painting their boat for one more year. This is very close to the expected monetary gain when considering the average annualized cost of painting a boat hull with copper. Since this figure was not achieved by asking this directly but instead was deduced from their choice behavior, it suggests that boaters behave rationally in their decisions regarding cost and are capable of calculating and comparing costs across prices.

(2) Boaters do not treat high-copper and low-copper paints differently. In other words, all other factors being held equal, boaters did not care if a paint was high copper versus low copper. Considering that the survey did not describe either of these two paint types as having a comparative advantage, other than the reduced amount of copper

leaching, this result is not surprising. It does, however, suggest that boaters do not see much value in marginal reductions in copper losses.

(3) Boaters are willing to pay about $500 more for having their boat painted with a non-toxic paint rather than copper, given identical performance characteristics with respect to how long the paint lasts and needs to be cleaned. They do not appear to value silicone and epoxy paints very differently. Silicone is valued a bit higher but the difference is not statistically significant. This suggests that there was not a large perceived difference in monetary value terms between the two different types of non-toxic paints. It is likely because we provided fairly similar descriptions of the two non-toxic paints; the silicone description emphasized slipperiness and fouling sliding off and the epoxy description emphasized the ability to be scrubbed hard.

(4) Boaters treat one-time conversion costs and paint application costs differently. When considering a paint that would require a certain one-time cost and an application cost every time the paint is applied, the subject did not simply add the costs together and consider them identically, although the reduction in weight put on one time conversion cost was not large.

V. Classification of Policy Options

All successful policies work in one of three ways: (a) educational efforts concerning the properties (*e.g.*, costs, environmental impacts, performance) of different hull coating options aimed at the boating industry and individual boaters, (b) raise the effective price of traditional copper-based hull coatings, and/or (c) reduce the price of alternatives to traditional copper-based hull coatings.

Educational Efforts

Educational efforts tend to fall into two categories: (a) demonstration projects aimed at boatyards and hull cleaners and (b) boater education projects.

Demonstration projects tend to serve two purposes. The first is to demonstrate the feasibility of undertaking particular actions or using technologies. This is sometimes referred to as the "proof of concept" phase. Such a demonstration project is being undertaken in conjunction with this project. The results from this demonstration project along with earlier San Diego efforts and information from other sources suggest that it is possible to move to the second step: determining how to move to the efficient, large scale commercial application phase.

This second step is clearly needed with various types of costs associated with non-toxic alternatives. While it has been demonstrated that non-toxic hull paintings can be put on boats and perform well, there are problems. Some non-toxic paints are considerably more difficult to apply and some have a poor quality physical appearance (in spite of looking good on test panels). This suggests a shift in the nature of a demonstration project toward determining how to best gear up for successful commercial application. The current demonstration project has also shown that some products fail. Information from earlier tests suggest that other products do not have a good track record over the longer term, although they may be well suited for particular groups of boats. There is also a need to create practical guidelines with the information that has been learned about the increased need for hull cleaning.

A commercial demonstration project is key to any long-term effort to phase out copper paints on hulls because boatyards now face considerable uncertainty with respect to the application of non-toxic alternatives. Because paint manufacturers are unwilling to bear the risks (other than replacement paint) when their hull coating products come off or must be removed, boatyards must effectively guarantee against such failures if they are to maintain their reputations with boaters as standing by the products they apply. The implication of having to make such a guarantee is either charging a higher price to cover the risk being taken or a reluctance to apply the non-toxic hull coatings. More boatyard experience will reduce this risk, and hence, lower prices and increase availability.

Boater education projects can have three general objectives. First, informing boaters that the copper hull paints they use cause pollution problems. Second, informing boaters of the long-term cost implications of copper versus non-toxic hull paint options. Third, to inform boaters about the merits of various hull cleaning procedures. The first of these objectives can help to encourage the use of non-toxic hull paints even if traditional copper paints have a cost advantage, as long as some boat owners are willing to pay a premium to help avoid doing environmental harm. The second of these objectives becomes critical when the use of non-toxic paints involve higher initial costs than copper paints, but appears to be financially beneficial to boat owners when a long term cost perspective is adopted. In this case, boat owners are likely to make decisions about the choice of what hull coating to use on the basis of incomplete or incorrect information. The third objective is important when hull cleaning practices can extend the life of current traditional copper hulls and when care for non-toxic hull paints differs from that of traditional copper paints.

A two year commercial demonstration project coupled with an extensive educational campaign is likely to be needed to ensure a smooth transition to non-toxic hull coatings.

Increase Effective Price of Copper Based Paints

The second way a successful policy can work is through increasing the price of copper based paints. The logic behind this sort of policy approach is simple. As the price of applying copper based hull paints increases relative to non-toxic alternatives, boaters will either switch to a non-toxic alternative or make the copper content of the paint go farther.

In the most extreme case, the regulatory authority imposes an immediate ban on the new application of copper-based paints. This is equivalent to setting an infinite price on copper paints, if the possibility of getting copper paint applied by a non-San Diego boatyard is ignored. Feasible implementation of such a policy requires sufficient boatyard capacity to move immediately to all non-toxic applications or a willingness of the regulator to see the number of boats reduced to the boatyard capacity constraint.

A prohibition on copper (either its application or its presence on a boat's hull) that is set far enough out in the future so that boatyard conversion capacity is not an issue, works by increasing the "resale" value of boats already converted to non-toxic hulls. That is because the cost of conversion for all boats will have to be incurred before the phase-out deadline, so that boats that have already been converted will be worth more. Such a policy works best if use of a non-toxic alternative is favorable from a cost perspective and if the conversion cost is not included, since the policy will force that cost to be incurred.

The price of copper hull paints can also be directly increased by the imposition of a user fee. The user fee should be based on the cuprous oxide content of the paint, thus providing an incentive for either switching to non-toxics or reducing the amount of copper that leaches off the boat over time. The latter can be done either by applying less copper initially to the boat's hull, given the same duration between repaintings, or by increasing the duration between repaintings, given the application of the same amount of copper initially.

An alternative to a user fee on copper is to set up a quota system limiting its use during a specified time period. If the copper quota is set below the level that would otherwise be demanded, boatyards will raise the price of applying copper until demand for copper-based hull coatings again equals supply. In this sense, a binding quota on copper use works in the same way as a user fee on copper. Indeed, if the regulator knows boater demand for copper hull coatings, it would be possible to set a copper user fee that would result in exactly the same amount of copper being used as allowed by a particular copper quota level.

With a copper quota, it is necessary to decide: (a) how to allocate the quota among boatyards and (b) whether to let boatyards buy and sell their initially obtained quotas among themselves. The most common way to do the original allocation of the overall quota is to auction it off in reasonably small units or to distribute the initial allocation to boatyards in proportion to current usage. As should be expected, this latter method is more popular with firms and tends to make a quota system run smoothly. Allowing firms to trade initial quota applications among themselves allows for adjustment to individual supply and demand shocks, and hence, makes the market more efficient which generally benefits both firms and consumers. This pollution control tool is often termed a marketable permit scheme and its use is becoming increasingly popular.

It is possible to vary copper user fees or quotas over time. If the price of copper and non-toxic alternatives were known and fixed, then the copper user fee should be increased over time or the copper quota should be decreased over time in order to reduce the number of recreational boats using copper hull coatings. When there is price or demand uncertainty, a copper quota that varies over time has the desirable property that it can be used to phase out copper use on a smooth schedule. A successful example of this tool was the use of marketable permits for lead in gasoline that declined in quantity over time to zero.

Reduce the Costs of Alternative Hull Coatings

One can also decrease the demand for copper hull coatings by reducing the relative costs of the non-toxic alternatives. Approaches in this category can all be considered to be subsidies of some aspect of the hull coating process. The most obvious is to subsidize the cost of non-toxic paints. Such a subsidy has the desirable effect of encouraging more boats to be painted with non-toxic paints. However, in general, this is not a desirable subsidy approach because one wants the cost of non-toxic paints to fall over time with more widespread use, which the subsidy will discourage. There are also issues involved in picking which non-toxic paint the subsidy will apply to, when one objective is to increase competition among paint manufacturers.

A different approach is to subsidize stripping costs. This is the labor side of the cost equation. There are three ways to do this, the first of which is a direct subsidy to the boatyard’s stripping fee. There are two drawbacks to this approach. It can encourage boatyards to raise rather than lower stripping charges or not to drop them as fast as they might otherwise do. With a complete phase-out of copper hulls and sufficient competition between boatyards it is not clear whether this is a substantive issue. More problematic, though, is that some of the subsidies will go to boat owners that would otherwise have to have their boats stripped. This makes a stripping subsidy less effective than a paint subsidy.

A different variant on a stripping subsidy is to provide below market rate loans for boat owners to have their boats stripped. Stripping costs are a large capital expenditure and to the extent that a boat owner is credit constrained, the boat owner will put off the stripping cost even if stripping now and repainting with a non-toxic would save money in the long run. Below market rate loans could also be offered as an inducement to strip and convert to non-toxics. Such below market rate loans suffer from the same problem as a direct stripping subsidy in that some boats that would have to be stripped anyway are subsidized.

The third variant of subsidy is to provide a price differential with respect to slip/ mooring costs. In this case, boats with non-toxic hull paints could be charged lower rates. Such a subsidy could be made revenue neutral by increasing “standard rates” to cover for the reduction in fees paid by boats with non-toxic hulls. This subsidy does not have the same problems as a paint or stripping subsidy but raises a number of administrative issues. It is important to note that, while this could be thought of as a subsidy for boats with non-toxic hulls, a revenue neutral measure also effectively increases the price for copper hull boats. Because of this property of providing an economic incentive to both groups of boats, this policy measure tends to be more effective than a pure subsidy. There is one other important aspect of this policy measure. It is dynamic in the sense that the lower monthly slip fee for having a boat with non-toxic hull paint continues over time.

VI. Policy Options Considered and Rejected

We considered a number of policy options. Some of these were rejected as either being dominated or not being able to meet the 66% reduction objective of the Regional Water Quality Board. Among the rejected options are: (a) an immediate conversion to non-toxic paints, (b) a dramatic reduction in the number of boats in San Diego Bay, (c) the large scale shift from traditional copper paints to low copper paints, and (d) the use of silicone based paints.

Immediate Conversion to Non-Toxics

We considered the policy option of banning the application of copper paint to boat hulls in San Diego Bay as a means of achieving immediate conversion to non-toxic hull paints within one repainting cycle. This policy option is ruled out as infeasible because there is not sufficient boatyard capacity to undertake converting enough boats to meet either the Regional Water Quality Board's 66% reduction or the complete copper phase-out objective. The fastest feasible conversion path is considered in Section VII. If the immediate conversion were feasible, our estimate is that this policy would cause boaters to incur extra costs of just over $33,750,000. This estimate is obtained by summing the epoxy-copper remaining lifetime cost differentials for the assumed population of 7,000 40-foot boats with uniformly distributed lifetimes over 30 years.

Substantially Reduce the Number of Boats

An impractical way to solve the copper problem in San Diego Bay is to reduce the number of boats so that the problem simply ceases to exist. The only two situations in which this option might be justified would be if (1) the cost of converting to non-toxic hull paints were prohibitively expensive, or (2) if that were the only way to achieve the desired environmental quality objective within the desired time frame. This policy option is infeasible because, as noted earlier, the cost of converting to non-toxic hull paints is not in fact prohibitively expensive. As shown below, the Regional Water Quality Control Board's TMDL objective could be met within a fairly quick time frame (*i.e.,* 5 years), so condition (2) does not apply either. As such, this policy option is dominated by other policy options and is not considered further.

Large Scale Transition to Low Copper

We next consider a large scale transition from traditional copper paints with 60% to 80% cuprous oxide levels to low-copper paints with 20% to 40% copper levels. Such a policy option held out the promise to very quickly reduce the copper pollution levels in San Diego Bay, for the simple reason that low copper paint can be painted over high copper paint. Hence, this policy option did not involve either the expense of stripping that is necessary for converting to non-toxic paints, nor did it involve the boatyard capacity constraints associated with the stripping. Furthermore, the application procedures for low-copper paints are similar to those for traditional copper paints.

In the best case scenario, applying a low-copper paint with 25% cuprous oxide to all boats (instead of applying traditional copper paints with 75% cuprous oxide) would meet the Regional Water Quality Board's 66% reduction objective over the course of one standard (2.5 year) repainting cycle. It would also be possible to move from this "low-copper" regime to a non-toxic regime to meet the complete phase-out objective. In this sense, the low-copper regime could either be permanent if it were deemed necessary only to meet the 66% reduction, or it could be transitional if deemed desirable to achieve the entirely non-toxic objective.

However, a more careful inspection of the low-copper option revealed fatal flaws. Low-copper paint is attractive (and the above logic holds) only if the amount of copper leached from boats painted with it is substantially lower than from boats painted with traditional (high) copper paints. This does not appear to be the case.

With non-ablative low copper paint, a boat needs to be painted more frequently (*e.g.*, every 12 to 15 months, according to the manufacturer of one low copper paint). Anecdotal evidence from local hull cleaners confirms this story: low-copper paint wears out quickly unless multiple coats of paint are used. With ablative low copper paints, manufacturers recommend applying more coats of paint, and this story is supported by the practice of one local boatyard with experience in applying such paints. With ablative paints, the copper is designed to slough off so that more layers of paint (up to a point) imply a longer lifespan of the hull coating. But quantity of copper released is now related to the number of layers of paint and the cuprous oxide content rather than just the cuprous oxide content which is largely the case with the standard single coat of traditional (non-ablative) copper paint. It is possible that some of this copper loss from ablative paints may occur outside of the harbor, since ablative paint is designed to slough off as the boat gains speed. This possibility is not considered in this report. Our conclusion regarding low-copper paints is that their copper loss profile over time appears to be quite similar to that of traditional copper paints, and as such, they do not provide a viable policy option for reducing copper content.

Large Scale Transition to Silicone

We also considered silicone-based paints. Silicone-based paints seem to be popular in Europe as an alternative to copper-based hull paint and have seen successful commercial application on some high-speed ferries. They often advertise increased performance (*i.e.*, speed) in addition to environmental benefits (*i.e.*, low copper and low VOC ratings). Paint costs range from being quite inexpensive for Pro Tect Water Shield (Miracle Cover), which is an anti-graffiti paint, to being quite expensive for Interlux's Veridian, which is specially formulated with respect to increasing a boat's speed.

Silicone coatings prevent adhesion of organisms because they provide a smooth and slippery surface that can release the attached organisms as a boat moves through the water. They are designed to slough off fouling growth on a hull, provided the degree of fouling is not high and the boat reaches a speed of 20 knots for a sustained period. This makes silicone paint ideal for particular types of boats, especially racing powerboats that are frequently taken out and run at high speeds.

The slipperiness of silicone paints can give boats increased speed through the water. While this slipperiness is indeed desirable in the water, it causes problems with handling boats in slips and by boatyards. Silicone appears to have a long lifespan but initial silicone paints were susceptible to cracks and fractures if hit by another boat or hard object.

Unfortunately, most boats in San Diego Bay are not taken out frequently nor run at high speeds. Initial formulations of silicone paints are very unforgiving if fouling growth builds up on the hull in the sense that they cannot withstand the aggressive scrubbing that epoxy coatings can. As such if a boat is not used at high speed on a regular basis, its hull should be cleaned as often as weekly in the summer. If this is not done and a hull becomes heavily fouled, the only recourse is to remove the silicone paint. Due to this problem and the cracking problem noted earlier, most of the boats painted with Veridian on San Diego Bay have been subsequently repainted with copper.

For most boaters, epoxy based paints currently dominate silicone as a non-toxic alternative. We do note, however, that there are a group of boaters for whom speed is paramount and who will therefore find that silicone-based paints best meet their needs. Recent limited experience with a second-generation silicone paint in the course of the demonstration project suggests that some of the major problems with silicone paints have been solved. As such silicone paints may be an attractive option for the future but will need more testing before they are commercially viable for large numbers of recreational boats.

Because the general cost and performance characteristics of silicone paints are similar to those of epoxy paints but less known, we will not formally consider silicone further in this report. The analysis preformed for epoxy is generally applicable with the caveat that silicone is likely to enjoy a small speed/fuel advantage not considered in this report and the disadvantage of requiring somewhat more frequent hull cleanings.

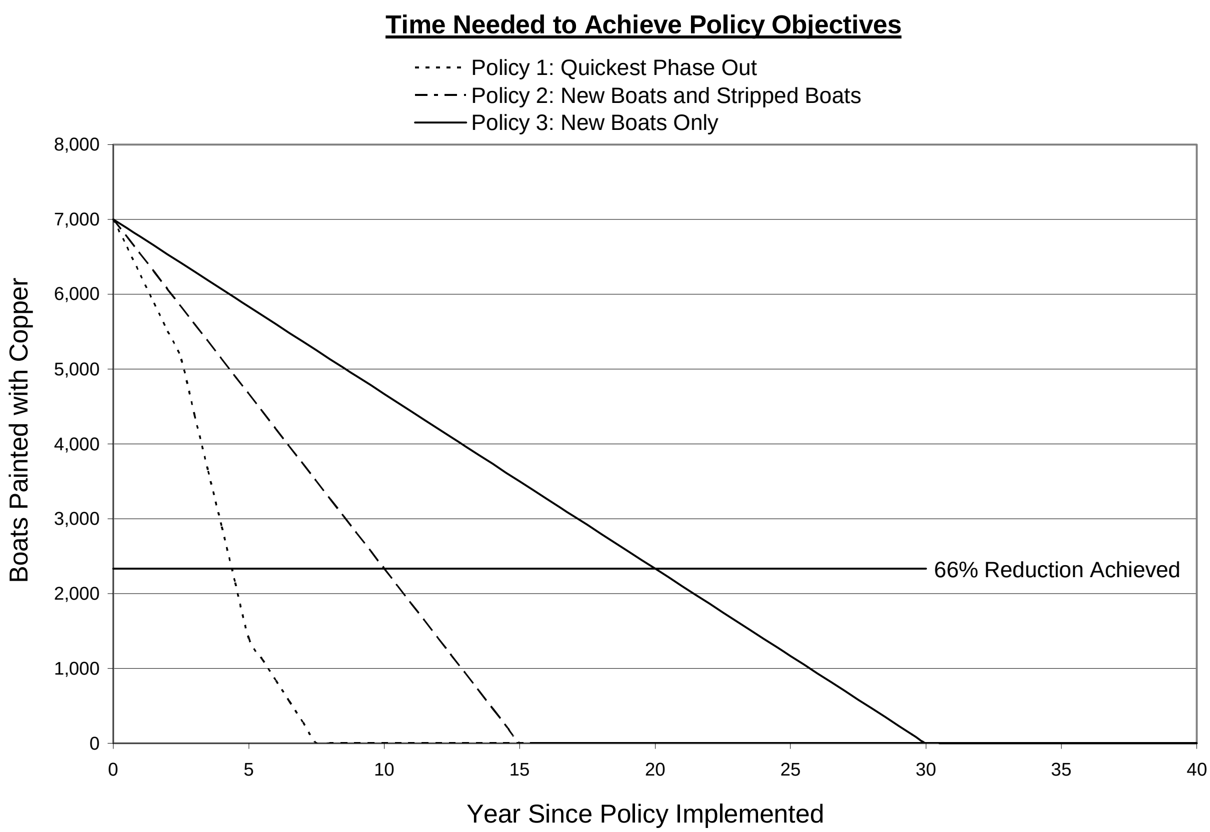
VII. Range of Time Paths for Feasible Policies

In considering feasible policies, it is first useful to ask what the effective range of time paths is for three such policies. Policy 1. One such policy is that which achieves the quickest phase-out time path. This path involves using all of the boatyard capacity to convert current copper hulled boats to non-toxics and insuring that all new boats are painted with non-toxic paints. This path meets the 66% reduction objective in about 5 years and the complete phase out in 7 years. It involves painting one thousand boats per year with non-toxic paints, with almost 800 of those being conversions.

Policy 2. Our earlier comparison between the cost of traditional copper and epoxy paints shows that the largest cost differential in favor of epoxy always occurs with new boats. This is because, when painting a new boat, you are avoiding the need to strip the old copper paint off. Epoxy, unlike copper, can continue to be painted over during the lifetime of the boat. Thus, the second policy option would only require that all new boats use non-toxic hull paints. Under our assumption of a 30-year boat life, this program would result in adding about 230 boats each year to the fleet of boats with non-toxic hull coatings. The 66% reduction objective would be met in just past 20 years, which is a substantially longer time period than most plans designed to correct a violation of a pollution standard. Furthermore, even though boats are assumed to have a 30-year average lifespan, some boats will have a much longer lifespan, implying that a complete phase-out of copper paints is likely to take 40 or 50 years. Due to the long time that would be necessary to meet our two objectives, this policy option will not be considered further.

Policy 3. After new boats, the next group of boats that has the most advantageous cost differential between epoxy and copper-based paints are the boats that currently need their old copper paint stripped off. Thus, the third policy option would require new boats to be painted with non-toxics and would ensure that boats that are being stripped anyway are also painted with non-toxics. In this case the complete phase-out would be expected to occur in 15 years. By this time, all old boats will have been stripped and repainted with a non-toxic hull coating and all new boats added to the fleet of boats will have been initially painted with a non-toxic hull coating. Thus, a 66% reduction objective would be achieved in roughly 10 years. Because policies following this time profile take advantage of the two types of boats with the most advantageous epoxy-to-copper cost comparisons, we will term such policies the "least cost policies". All of the feasible policies we consider fall between the quickest time and the least cost policies.

FIGURE 4



VIII. Policies Achieving Objectives in Quickest Time

The quickest time that a feasible policy can achieve the 66% reduction objective is five years, and the quickest time for achieving the complete phase-out objective is seven years. The constraint on how fast these two objectives can be met is boatyard capacity. All of the quickest time policy options fully utilize all of the current boatyard capacity that is being devoted to hull maintenance plus a 10% increase in the current level of capacity utilization for the purpose of hull conversion. 10% excess boatyard capacity is a very ambitious assumption and requires that the program undertaken never fall behind.

Under this policy it is assumed that all new boats will be painted with a non-toxic alternative. That is because under the assumptions that we use (i.e., a $40 per square foot cost for epoxy paint and a 7.5 year hull paint duration), boat owners save money by using epoxy. There are probably some people who would want copper even though it has higher lifetime costs. The requirement that all new boats use non-toxics avoids this issue. Under the cost assumptions made, new boat owners save in aggregate about $450 thousand by painting with epoxy.

Quickest time policies require converting a much larger number of boats than this, particularly in early years of the program. There are several ways to select these boats.

One way might be some random selection mechanism such as a lottery. This could be done within each marina/mooring location with a requirement that the boats chosen be converted. The random selection here is assumed to be with respect to existing boats, with all new boats required to be painted with non-toxic hull paint. Because the boats that need to be converted are picked randomly, the cost to boat owners is simply the "average" of the remaining lifetime cost differentials between epoxy and copper with each randomly chosen boat being stripped and painted with epoxy. An advantage of the lottery approach is that the "cost" of the policy (to boaters) is the actual conversion costs of the boats chosen. Conversion using this approach imposes a cost of about $25 million on existing boat owners. This is less than the $34 million cost of the infeasible immediate-conversion policy, because there is the opportunity for more new boats to be painted with non-toxics.

Such a policy might be dominated by a policy that “selects” as volunteers the boats that are fairly close to needing to be stripped. Policy options of this kind fall into the two categories discussed earlier (*i.e.*, increase the price of copper or decrease the cost of non-toxic alternatives). The drawback of increasing the price of copper is that the price of copper would increase for all boat owners who are using copper, not just for those for whom a small change in the copper price would make epoxy the more attractive choice. The drawback of decreasing the cost of non-toxic alternatives (the subsidy approach) is that the same subsidy has to be offered to all existing boats that convert to non-toxics, despite the fact that some boats would have switched to epoxy with a very small subsidy.

A policy that increases the price of copper hull repainting could be achieved in just under $20 million to existing boaters. This is a smaller cost than the $25 million from a random lottery policy. The effective increase in the cost of copper repainting that results in achieving the quickest time path is $32.00 per square foot, or an increase in the cost of repainting with copper of approximately $1,200.

As noted earlier, one can directly increase the price of copper through a user fee on the paint. However, perhaps the most effective alternative for increasing the price of copper would be a marketable permit scheme whereby the total amount of copper allowed each month is the amount needed to keep the program on target. To make the marketable permit system more flexible, boatyards could carry forward any part of the previous month’s allocation not used and borrow from the next month’s allocation. Allowing trading of monthly copper allocations between boatyards further increases flexibility. The advantage of a quota-based permit trading system over a direct price increase is that it ensures that the program stays on track over any period of several months or longer.

All of the possible subsidy oriented policies involve considerably more uncertainty because they rely upon how many boaters accept the subsidy. If too few accept the subsidy, the quickest path objective cannot be achieved due to the boatyard capacity constraints. If too many accept the subsidy, boatyard capacity still limits the number of boats converted but the amount paid for conversions is higher than necessary. A paint subsidy in this case is hard to fine-tune. A stripping subsidy is easier to fine-tune because it can be adjusted in response to the number of subsidy acceptances.

The main difficulty with a stripping subsidy is that it is impossible to discriminate between boats that need to be stripped and those that almost need to be stripped. Further, in the same time period, all boats that are stripped and converted will have to be paid equal subsidies. The subsidy that will need to be paid is that which induces the last needed boat to strip and convert to epoxy. Assuming the same subsidy is paid in all years, the cost of the subsidy to the subsidizing agency would be approximately $22 million dollars. The subsidy payment that would need to be paid to those converting would be different in each six-month period of the policy, ranging from around $2,000 per 40-foot boat in the early periods to almost $7,000 per 40-foot boat in the last period. In this sense, the subsidy approach is less efficient than approaches that increase the price of copper ($16 million), but the party who pays is different.

It should be noted that this estimate of the subsidy policy's cost assumes that a boat needing to be stripped should be stripped immediately. If one allows for the possibility that boaters could put off stripping to exploit the higher subsidies in later periods, then the cost of this policy would be considerably higher (close to $34 million).

On the other side, the policy cost estimate requires that in the late period of the program, the subsidy is targeting boats in the very last years of their 30-year lifespan. These boats are very expensive with respect to the incentive needed to convert (hence the subsidy nears $7,000 in late periods), and they will be retiring in only one or two years anyway. If one allows for the possibility of waiting for these boats to retire rather than converting them in the last year or two of their lives, the policy would be considerably less expensive.

If the subsidy to boats that have to be stripped anyway could be avoided then the total cost of the subsidy would be just over $13 million.

A slip/mooring subsidy for boats with non-toxic hulls would have to charge a lower cost to all new boats, boats that were going to be stripped and converted without any subsidy, and those who are induced to strip and convert due to the subsidy. As such, this subsidy approach is yet another way to induce conversion to non-toxics in terms of total costs.

The possible advantage of the program is that it does not involve any direct subsidy cost to a government agency. While it is possible to determine a revenue neutral policy in terms of the expected number of conversions, there will be some uncertainty concerning the precise number of boats that are induced to convert and in the distribution of boats with non-toxic hull paint among boat yards.

It is possible that any of the policies achieving the 66% reduction in the quickest time could be enhanced in the sense of shortening their time, if hull cleaning practices can be identified that lengthen the average time between when copper hull paint needs to be repainted. This statement is also true of the time required by other feasible policies.

XI. Policies Achieving Objectives at Least Cost

Policies achieving the objectives at the least cost meet those objectives only by explicitly requiring new boats and effectively requiring all boats that need to be stripped to convert to non-toxic hull coatings. Policies in this class are the least costly because the cost difference between copper and non-toxics is most advantageous to non-toxics when stripping costs do not have to be incurred to use the non-toxic alternative. Stripping costs do not have to be incurred on either new boats (since they have only a gel coat with hull paint typically being applied at a local boatyard) and on boats that have to be stripped anyway (because of the build-up of old copper paint layers).

If non-toxics have a less expensive lifetime cost for stripped boats, it may be in a boat owner's interest to have their boat stripped earlier than would normally be the case. If this condition holds, the least cost policy may result in meeting the desired objectives faster than would be true if only new and stripped boats moved to non-toxic hull paint.

With our standard assumptions about copper and epoxy (i.e., $30 a square foot and 7.5 years duration respectively), fully informed consumers, and a ban on boats in San Diego Bay with copper hulls, the least cost policy achieves the objective at a cost to boaters of approximately $1.5 million. The cost incurred by existing boats is just over $2.4 million, while the gain to new boats is about $900,000. With slightly more optimistic assumptions about the epoxy, the cost effectively goes to zero. The reason for this dramatic reduction in costs relative to the $20-$26 million dollar range for quickest time policies is that it is optimal for boats to always be painted with epoxy when the epoxy-copper cost differential is most favorable. The cost for the 66% reduction objective is only about $800,000 less than the cost for the complete phase-out.

It is interesting to look at variations on the quickest time policy which do not formally ban boats with copper hulls at the end of 15 years. There are several relevant "conditions" under which specific versions of such a policy might be implemented.

Case 1

First consider the equal cost, full information, non-toxic preference case where:

(1) non-toxics have the same total costs as copper if stripping is not necessary,
(2) all boat owners are aware of (1), and
(3) boat owners prefer non-toxics to copper at equal cost.

Under these conditions, boat owners voluntarily select non-toxic paints when they buy new boats and have their old stripped boats painted with non-toxics. This policy works by adding about 500 boats with non-toxic hull coatings to the fleet of recreational boats on San Diego Bay each year. About half of these boats are new boats that replace old boats and about half of these boats are old boats that are stripped and repainted with non-toxic paints. Under these conditions, this policy would achieve the 66% objective within 10 years.

Ignoring the natural time variability in the need to strip old boats, a total phase-out of copper paints would be expected within 15 years. Variability in the need to strip off old paint will extend the final phase-out time period beyond 15 years, but the number of boats with copper paint would be fairly small.

Case 2

Now modify the Case 1 conditions so that non-toxics have a lifetime cost advantage, which may at present be true and is likely to be true in the future as the cost of non-toxic paint falls with greater production and the labor/equipment cost of application falls as more experience is gained.

Under the conditions of this case, new boat owners and those who have to strip their hulls will save money by using non-toxics. If the cost savings from non-toxics are sufficiently large, boat owners whose hulls will soon need to be stripped will have an economic incentive to have their hulls converted to non-toxics one or more periods earlier than under Case 1. This will have two implications. First, ignoring time variability in the need to strip a boat's hull, the expected time needed to achieve a complete copper phase-out will be closer to 12 years. Second, the natural variability in the point at which a hull needs to be stripped will tend to push this date later but the number of boats with copper hulls will be relatively small because most boat owners will find that they save money by going ahead with early stripping and conversion to non-toxics. The time period for achieving the 66% reduction will also be pushed earlier to approximately 8 years. This date will be less affected by variability in the time at which stripping is needed.

Case 3

Now modify the conditions of Case 1 (or Case 2) so that some boat owners are not aware of the equal (or lower) costs of non-toxics. The lack of cost information will now cause some boat owners to pick copper on either new boats or stripped boats when they would have saved money by picking a non-toxic alternative. As such, the dates by which a 66% reduction and a total phase-out of copper occur will be pushed back.

The extent of this push-back will depend upon the nature of the information difficulties and how widespread they are. The typical assumption is that informational difficulties are likely to be more prevalent during the early periods and are eliminated over time. If this is so, then the 66% reduction and total phase-out will be achieved voluntarily but at later dates. The 66% reduction is likely to be met not much later than under Case 1, but total phase-out will take considerably longer.

One of the main implications of this case is that costs will be higher if boaters do not take advantage of the opportunity to convert to non-toxic hull paints at the optimal time, and instead simply have their boats stripped and repainted with copper. If this is the case, then there will be "expensive" conversions near the end of any phase-out date. Avoidance of these expensive conversions should be one of the main focuses of an educational effort.

Case 4

Now modify the conditions of Case 1 so that some owners have a preference for copper at an equal cost. In this case, the use of copper paints will never be phased out. If more than a third of boat owners prefer copper at an equal cost, the 66% reduction objective will not be met either. This case helps to illustrate that if non-toxics do not have an absolute cost advantage, and in the absence of either a phase-out date or a policy that changes the relative prices of copper versus non-toxics, neither policy objective may be met through a strictly voluntary program.

X. Blended Policy Options

It is possible to achieve the 66% and complete phase-out objectives at any time between the quickest time policy options and the least cost policy options.

The key regulatory tool for doing this is the date set for banning copper hulls in San Diego Bay. For instance, if the date for banning copper hulls was set at 12 years in the future, it would be optimal for boats that would have ordinarily been stripped in years 13 through 15, to be stripped in year 15. Because most boats would have already been converted, boatyard capacity is not a binding constraint in such conversions. Further, for our analysis on conversion costs discussed later, the group of boats that have the most favorable non-toxic to copper cost comparison after new boats and boats that were being stripped anyway are boats that will soon be stripped. If non-toxics do not enjoy an absolute cost advantage for soon to be stripped boats, then no boats will be stripped earlier except for those whose "stripping date" falls after the date for banning boats with copper-based hull paints.

The estimates that we have provided are for a complete phase-out. A useful question to ask is whether the costs are disproportionately smaller for a 66% reduction. The answer here is no. The cost estimate of a 66% reduction for all three of these policies is 72% of the cost of a complete phase-out policy. The reason for this is that costs of all three of these policy options are at their most expensive in the early years. Over time, new boats with non-toxic hull coatings become a larger fraction of the fleet and more older boats reach their "natural" optimal stripping time.

The one possibility for considerably reducing the cost of the quickest time policies for a 66% reduction would appear to be through the implementation of hull cleaning practices that substantially prolong the life of current copper paint. Such a policy could not be used by itself since even the most optimistic of the claims made in this area (*i.e.,* going from our current painting interval of 2.5 years to 6 years) would only result in a 42% decrease in copper. However, if one were willing to accept the same 5-year time period, other alternatives become possible. The drawback is the lack of any solid research that would allow reasonable statements to be made about what is possible in this regard, as was noted earlier. If there are gains to be made with respect to extending the life of copper paints with hull cleaning practices, requirements that such practices be implemented could also be used in conjunction with the other policies that are considered below in order to potentially reduce the cost of achieving the 66% reduction objective.

XI. Burden on Other Parties

Monitoring and Enforcement Issues

Any policy that requires various parties to undertake actions will require some form of monitoring and enforcement. The policies considered generally require these actions with respect to one or more of the following:

(a) ensuring that only non-toxic hull coatings are applied to new boats,
(b) ensuring that only non-toxic hull coatings are on boats on San Diego Bay after a particular date,
(c) ensuring that only a specific total amount of copper is applied to recreational boats over some time period,
(d) ensuring that a “user fee” is collected on copper hull coatings applied,
(e) ensuring that boats for which a stripping subsidy is paid are actually converted from copper to non-toxic hull coatings, and
(f) ensuring that either a discount on slip/mooring fees is offered to boats with non-toxic hulls or that a surcharge is imposed on those with copper paints.

Each of these will be taken up in turn.

Given the relatively small number of boatyards, there is unlikely to be much of a problem with the application of non-toxic paints to new boats except in the following two related circumstances. The first will be when a new boat owner insists on having copper applied to the new hull. The second will be when a “new” boat comes into San Diego Bay with copper already applied. The two are similar in that if San Diego boatyards refuse to apply copper to new boats, the new boat owner can have copper applied either before the boat arrives or by a boatyard outside of San Diego. An educational effort aimed at providing information to yacht brokers and perspective new boat owners that they would save money over the long run with the application of a non-toxic hull coating would likely reduce these two sources of “leakage” from working on reducing copper hull paint from the top down (new boats) and the bottom up (stripped old boats). A major problem would occur only if San Diego boatyards applied copper to a large fraction of new boats. This problem could probably be avoided by having boatyards agree with the Port District or Regional Water Quality Control Board to not apply copper hull paints to any new boats.

Ensuring that there are no boats in slips or mooring locations in San Diego Bay with copper hull paint after some specified date could be done in two different ways. The first would be to have the boatyard applying the non-toxic hull coating provide a certificate to this effect. Such a certificate could also be issued upon inspection by a San Diego boatyard (*e.g.,* a boat with a non-toxic hull coating moving to San Diego might need to get a non-toxic certificate). Marinas and mooring companies would be required to have copies of such certificates in their possession on the specified phase-out date. This program would work in a manner similar to marina requirements for insurance certificates. The Port District would need to provide some sort of check that marinas/mooring companies had non-toxic hull coating certificates on hand for all their boats. The second approach would be to have a one-time physical inspection of boat hulls at each marina/mooring location soon after the announced phase-out date. The inspection would be required by each marina/mooring location as a condition of keeping the boat there. The marina/mooring location would then certify that each boat that remained at the location had non-toxic hull paint.

Ensuring that no more than a specified amount of cuprous oxide is applied to boat hulls in a specified time period (*e.g.*, a year), requires a method of recording how much cuprous oxide is applied by each boatyard. The overall quota can be met in one of two ways. First, by giving each boatyard an individual quota for the time period, which the boatyard cannot exceed. The second is by giving each boatyard an individual copper allocation at the beginning of the period with the sum of the allocations over the boatyards equal to the total allowed amount of copper that could be applied to boats. Boatyards would be free to allocate among themselves. While this approach is more flexible and will benefit both boat owners and boatyards, it is necessary to implement a system for recording the trades of the initial copper allocations among boatyards.

There are minor monitoring issues associated with paying part of the stripping costs for boats in that it is possible to reapply copper paints to such boats. This problem can be dealt with by making the subsidy available only if the boatyard also applies non-toxic hull paint to the boat. The boatyard could be required to certify that this was the case and the government agency paying the subsidy could be given audit ability with respect to the relevant records and boats.

Slip/mooring cost differentials (*i.e.*, a lower price offered to those using non-toxic hull paints or a higher price to those using copper) provides an incentive to boat owners to convert to non-toxic hull paints. Implementation of such a policy requires that one be able to identify which boats have non-toxic hull paints. These requirements are similar to those noted above under the discussion of certification at a specified phase-out date for copper hull paint on recreational boats.

Equipment and Training

For boatyards there are some issues related to ramping up for large-scale application of non-toxic hull paints. These issues have been discussed at some length in the section on the need for demonstration projects.

For hull cleaners it is clear that special training and, probably, special equipment will be needed to either prolong the life of copper-based hulls or to clean non-toxic hulls. Because the training and equipment are likely to make hull cleaners more efficient, particularly coupled with the need for more frequent hull cleaning, the long run financial implications of this training and equipment are likely to be neutral. However, such training and equipment requirements are likely to impose substantial “upfront” expenditures on hull cleaners.

Financial Costs

The most obvious financial costs not accruing to individual boat owners are the changes in revenue to boatyards and hull cleaners. Under almost any of the policy options, boatyards will experience an increase in business as old hulls are stripped and painted with non-toxic paint. Over longer time horizons, boatyards will experience a reduction in their hull painting business since it will be necessary to paint non-toxic hulls less often. The different policy options will influence how fast this happens. Over very long time horizons, this change is likely to occur in the absence of any change in policy because of the long run cost advantage to boat owners of non-toxic hull coatings. For hull cleaners, any of the policy options will result in increased revenue because of the need for more frequent hull cleanings with non-toxic paints.

For marinas and mooring locations there might be financial costs under two different policy options. The first of these is the offering of a slip/mooring price differential. Such a price differential could be set to be “revenue neutral” with a lower price to non-toxic hulled boats being offset with a higher price being charged to those with copper hulls. Because the exact number of boats of each type at any point in time will be unknown to the marina/mooring location, there will always be the potential for some loss (or gain) in revenue relative to what was expected. There are also likely to be some administrative costs involved with any requirement to marinas/mooring locations to have certificates for non-toxic hulls on file and of obtaining the initial certificates.

For government agencies, fiscal costs are likely to occur in four areas. The first is any funding of demonstration projects. This cost is directly related to the number and size of the boats on which non-toxic hull paints are applied and to what fraction are new boats versus stripped boats. The second is the cost of any educational activities that are undertaken. The third are any subsidies that are provided after the demonstration periods to encourage the application of non-toxic paints by either paying for part of the stripping or painting costs. Such costs are directly related to their magnitude and the number of boats made eligible for them. The fourth is any revenue that is collected via the imposition of user fees on copper hull paints.

XII. Recommendations

Any effective policy will need to have two elements: (a) a requirement that all new boats be required to use non-toxic hull coatings and (b) a definitive date by which copper hull coatings in San Diego Bay will not be allowed. Coupled with a good commercial demonstration plan and an effective boater education program, this may be almost sufficient to achieve a desired time objective. Use of marketable copper permits that decline in value would ensure that the program was kept on track.

Implementation of a quickest time program would be difficult given various uncertainties concerning non-toxic paint prices and performance. Its administrative implementation is also difficult unless boaters respond exactly as desired, which is unlikely. They are dramatically more expensive than the least cost policy option. All of this suggests that a slower approach is more practical. Indeed, under favorable conditions, implementation of the least cost approach (with the elements noted above) is likely to achieve the 66% reduction earlier and largely phase-out the use of copper before the ban date. The least cost approach is fairly forgiving to problems in the early years of the program, particularly if the level of copper allowed by the marketable permits in those years is fairly high (with a corresponding reduction in the middle and later years of the program). Under what we believe to be the most likely case with respect to the cost of non-toxic hull paints and their maintenance, boat owners will save small amounts of money on hull costs when those costs are (correctly) looked at over the course of a boat's life. Under quite pessimistic assumptions, boat owners will spend a small amount more money on hull maintenance costs under an eventual ban on the use of copper hull paints but the amount will be small relative to overall hull maintenance costs.

APPENDICES AND FIGURES

Appendix A1: Locations of Recreational Boats in San Diego Bay, Mission Bay, Oceanside, and Dana Point

Marina Name	**Location**	**Number of Slips**
California Yacht Marina	Chula Vista	365
Chula Vista Marina	Chula Vista	561
Coronado Cays Yacht Club	Coronado	56
Coronado Yacht Club	Coronado	265
Fiddlers Cove (Military Marina)	Coronado	264
Glorietta Bay Marina	Coronado	106
Loews Coronado Bay Resort	Coronado	80
San Diego Marriott Marina	Downtown	446
Cabrillo Marina	Harbor Island	450
Harbor Island West	Harbor Island	620
Marina Cortez	Harbor Island	525
Sheraton Harbor Island Marina	Harbor Island	45
SunRoad Resort Marina	Harbor Island	610
Dana Inn and Marina	Mission Bay	140
Dana Landing	Mission Bay	90
Driscoll-Mission Bay Marina	Mission Bay	220
Marina Village Marina	Mission Bay	634
Oceanside Harbor	Oceanside	876
Dana Point Marina	Dana Point	1476
Dana West Marina	Dana Point	981
Bay Club	Shelter Island	149
Half Moon Anchorage	Shelter Island	183
San Diego Yacht Club	Shelter Island	576
Shelter Cove Marina	Shelter Island	160
Shelter Island Marina	Shelter Island	169
Shelter Pointe Hotel and Marina	Shelter Island	523
Silvergate Yacht Club	Shelter Island	150
Southwestern Yacht Club	Shelter Island	382
Sun Harbor Marina	Shelter Island	120
San Diego Mooring Co.	America’s Cup Harbor	170
San Diego Mooring Co.	Coronado	69
San Diego Mooring Co.	Laurel Street	154
San Diego Mooring Co.	Shelter Island	44
Fiddlers Cove (Military Mooring)	Coronado	100

Appendix A2: Recreational Boat Types and Sizes in San Diego Bay, Mission Bay, Oceanside, and Dana Point

Location	Marina Information / Slip #	Boat Information					
Chula Vista:							
	California Yacht Marina:	*Powerboats:*	146	*Sailboats:*	219	*Range:*	23' - 58'
	Number of Slips: 365	*20' to 29':*	40	*20' to 29':*	60		
	640 Marina Parkway	*30' to 39':*	40	*30' to 39':*	60		
	Chula Vista, Ca 91910	*40' to 49':*	52	*40' to 49':*	78		
	Phone: (619) 422-2595	*50' to 59':*	14	*50' to 59':*	21		
	Fax: (619) 422-2696	*>60':*	0	*>60':*	0		
	Chula Vista Marina:	*Powerboats:*	224	*Sailboats:*	337	*Range:*	15' - 65'
	Number of Slips: 561	*20' to 29':*	60	*20' to 29':*	91		
	550 Marina Parkway	*30' to 39':*	74	*30' to 39':*	111		
	Chula Vista , Ca 91910	*40' to 49':*	73	*40' to 49':*	108		
	Phone: (619) 691-1860	*50' to 59':*	17	*50' to 59':*	27		
	Fax: (619) 420-9667	*>60':*	10	*>60':*	15		
Coronado:							
	Coronado Cays Yacht Club:	*Powerboats:*	30	*Sailboats:*	26	*Range:*	20' - 60'+
	Number of Slips: 56	*20' to 29':*	0	*20' to 29':*	8		
	30 Caribe Cay Blvd.	*30' to 39':*	9	*30' to 39':*	14		
	Coronado, Ca 92118	*40' to 49':*	1	*40' to 49':*	2		
	Phone: (619) 429-0133	*50' to 59':*	10	*50' to 59':*	2		
	Fax: (619) 424-5938	*>60':*	10	*>60':*	0		
	Coronado Yacht Club:	*Powerboats:*	132	*Sailboats:*	133	*Range:*	20' - 60'+
	Number of Slips: 265	*20' to 29':*	37	*20' to 29':*	38		
	1631 Strand Way	*30' to 39':*	50	*30' to 39':*	50		
	Coronado, Ca 92118	*40' to 49':*	30	*40' to 49':*	30		
	Phone: (619) 435-1848	*50' to 59':*	13	*50' to 59':*	13		
	Fax: (619) 435-2480	*>60':*	2	*>60':*	2		
	Glorietta Bay Marina:	*Powerboats:*	53	*Sailboats:*	53	*Range:*	20' - 60'
	Number of Slips: 106	*20' to 29':*	13	*20' to 29':*	13		
	1715 Strand Way	*30' to 39':*	13	*30' to 39':*	14		
	Coronado, Ca 92118	*40' to 49':*	14	*40' to 49':*	13		
	Phone: (619) 435-5203	*50' to 59':*	10	*50' to 59':*	11		
	Fax: (619) 435-5377	*>60':*	3	*>60':*	2		
	Loews Coronado Bay Resort:	*Powerboats:*	60	*Sailboats:*	20	*Range:*	30' - 60'+
	Number of Slips: 80	*20' to 29':*	0	*20' to 29':*	0		
	4000 Coronado Bay Road	*30' to 39':*	0	*30' to 39':*	20		
	Coronado, Ca 92118	*40' to 49':*	20	*40' to 49':*	0		
	Phone: (619) 575-7245	*50' to 59':*	30	*50' to 59':*	0		
	Fax: (619) 424-4456	*>60':*	10	*>60':*	0		
Dana Point:							
	Dana Point Marina:	*Powerboats:*	890	*Sailboats:*	586	*Range:*	20'-85'

Number of Slips: 1476	*20'-29':*	475	20'-29':	225
34555 Casitas Place	*30'-39':*	165	30'-39':	170
Dana Point, Ca 92629	*40'-49':*	130	40'-49':	120
Phone: (949) 496-6137	*50'-59':*	75	50'-59':	45
Fax: (949) 496-0788	*60'-69':*	35	60'-69':	18
	70'-79':	9	70'-79':	7
	>80':	1	>80':	1

Dana West Marina:	*Powerboats:*	391	*Sailboats:*	590	*Range:*	22'-60'
Number of Slips: 981	*20' to 29':*	250	*20'-29':*	410		
24500 Dana Point Harbor Drive	*30'-39':*	65	*30'-39':*	95		
Dana Point, Ca 92629	*40'-49':*	26	*40'-49':*	35		
Phone: (949) 493-6222	*50'-59':*	35	*50'-59':*	30		
Fax: (949) 493-7531	*60':*	15	*60':*	20		

Downtown:

San Diego Marriott Marina:	*Powerboats:*	312	*Sailboats:*	134	*Range:*	30' - 120'
Number of Slips: 446	*20' to 29':*	0	*20' to 29':*	0		
333 West Harbor Drive	*30' to 39':*	181	*30' to 39':*	80		
San Diego , Ca 92101	*40' to 49':*	91	*40' to 49':*	40		
Phone: (619) 230-8955	*50' to 59':*	30	*50' to 59':*	14		
Fax: (619) 230-8958	*>60':*	10	*>60':*	0		

Harbor Island:

Cabrillo Marina:	*Powerboats:*	242	*Sailboats:*	208	*Range:*	10' - 60'+
Number of Slips: 450	*20' to 29':*	20	*20' to 29':*	15		
1450 Harbor Island Drive	*30' to 39':*	112	*30' to 39':*	90		
San Diego, Ca 92101	*40' to 49':*	46	*40' to 49':*	72		
Phone: (619) 297-6222	*50' to 59':*	54	*50' to 59':*	24		
Fax: (619) 299-8446	*>60':*	10	*>60':*	7		

Harbor Island West:	*Powerboats:*	155	*Sailboats:*	465	*Range:*	21' - 100'
Number of Slips: 620	*20' to 29':*	25	*20' to 29':*	76		
2040 Harbor Island Drive	*30' to 39':*	82	*30' to 39':*	247		
San Diego, Ca 92101	*40' to 49':*	28	*40' to 49':*	85		
Phone: (619) 291-6440	*50' to 59':*	12	*50' to 59':*	35		
Fax: (619) 291-2684	*>60':*	8	*>60':*	22		

Marina Cortez:	*Powerboats:*	210	*Sailboats:*	315	*Range:*	25' - 60'
Number of Slips: 525	*20' to 29':*	39	*20' to 29':*	59		
1880 Harbor Island Drive	*30' to 39':*	107	*30' to 39':*	159		
San Diego, Ca 92101	*40' to 49':*	32	*40' to 49':*	48		
Phone: (619) 291-5985	*50' to 59':*	17	*50' to 59':*	26		
Fax: (619) 291-9136	*>60':*	15	*>60':*	23		

Sheraton Harbor Island Marina:	*Powerboats:*	29	*Sailboats:*	16	*Range:*	35' - 60'+
Number of Slips: 45	*20' to 29':*	0	*20' to 29':*	0		
1380 Harbor Island Drive	*30' to 39':*	4	*30' to 39':*	2		
San Diego, Ca 92101	*40' to 49':*	5	*40' to 49':*	3		
Phone: (619) 692-2249	*50' to 59':*	10	*50' to 59':*	5		

Fax: (619) 692-2339	*>60':*	10	*>60':*	6		

Sunroad Marina:	*Powerboats:*	366	*Sailboats:*	244	*Range:*	30' - 65'
Number of Slips: 610	*20' to 29':*	0	*20' to 29':*	0		
955 Harbor Island Drive	*30' to 39':*	98	*30' to 39':*	67		
San Diego, Ca 92101	*40' to 49':*	179	*40' to 49':*	115		
Phone: (619) 574-0736	*50' to 59':*	74	*50' to 59':*	53		
Fax: (619) 574-7603	*>60':*	15	*>60':*	9		

Military Marinas:

Fiddler's Cove:						
Number of Slips: 264	*Powerboats:*	42	*Sailboats:*	238	*Range:*	25' - 45'
Number of Moorings: 100	*20' to 29':*	5	*20' to 29':*	29		
NASNI MWR Code 92	*30' to 39':*	32	*30' to 39':*	180		
Box 357081	*40' to 49':*	5	*40' to 49':*	29		
San Diego, Ca 92135-7081	*50' to 59':*	0	*50' to 59':*	0		
Phone: (619) 522-8680	*>60':*	0	*>60':*	0		
Fax: (619) 522-7969						
	Powerboats in moorings:	15	*Sailboats in moorings:*	85		

Mission Bay:

Dana Inn and Marina:	*Powerboats:*	66	*Sailboats:*	73	*Range:*	20' - 49'
Number of Slips: 140	*20' to 29':*	29	*20' to 29':*	71		
1710 West Mission Bay Drive	*30' to 39':*	32	*30' to 39':*	2		
San Diego, Ca 92109	*40' to 49':*	5	*40' to 49':*	0		
Phone: (619) 222-6440 - x 3146	*50' to 59':*	0	*50' to 59':*	0		
Fax: (619) 222-5916	*>60':*	0	*>60':*	0		

Dana Landing:	*Powerboats:*	81	*Sailboats:*	9	*Range:*	8' - 50'
Number of Slips: 90	*20' to 29':*	11	*20' to 29':*	1		
2590 Ingraham Street	*30' to 39':*	54	*30' to 39':*	6		
San Diego, Ca 92109	*40' to 49':*	7	*40' to 49':*	1		
Phone: (619) 224-2513	*50' to 59':*	9	*50' to 59':*	1		
Fax: (619) 224-1076	*>60':*	0	*>60':*	0		

Driscoll-Mission Bay Marina:	*Powerboats:*	97	*Sailboats:*	123	*Range:*	25' - 90'
Number of Slips: 220	*20' to 29':*	10	*20' to 29':*	12		
1500 Quivera Way	*30' to 39':*	49	*30' to 39':*	47		
San Diego, Ca 92109	*40' to 49':*	38	*40' to 49':*	56		
Phone: (619) 223-5191	*50' to 59':*	0	*50' to 59':*	6		
Fax: (619) 223-5098	*>60':*	0	*>60':*	2		

Marina Village:	*Powerboats:*	390	*Sailboats:*	244	*Range:*	25' - 50'
Number of Slips: 634	*20' to 29':*	164	*20' to 29':*	138		
1936 Quivera Way	*30' to 39':*	159	*30' to 39':*	80		
San Diego, Ca 92109	*40' to 49':*	51	*40' to 49':*	24		
Phone: (619) 224-3125/921-9349	*50' to 59':*	16	*50' to 59':*	2		
Fax: (619)226-4260						

Oceanside:

Oceanside Harbor:	*Powerboats:*	438	*Sailboats:*	438	*Range:*	26' - 51'
Number of Slips: 876	*20' to 29':*	228	*20' to 29':*	228		
1540 Harbor Dr.	*30' to 39':*	145	*30' to 39':*	144		
Oceanside, Ca 92054	*40' to 49':*	53	*40' to 49':*	54		
Phone: (760) 435-4000	*50' to 59':*	12	*50' to 59':*	12		
	>60':	0	*>60':*	0		

Shelter Island:

Bay Club:	*Powerboats:*	41	*Sailboats:*	108	*Range:*	20' - 60'+
Number of Slips: 149	*20' to 29':*	8	*20' to 29':*	24		
2131 Shelter Island Drive	*30' to 39':*	22	*30' to 39':*	54		
San Diego, Ca 92106	*40' to 49':*	9	*40' to 49':*	24		
Phone: (619) 222-0314	*50' to 59':*	0	*50' to 59':*	5		
Fax: (619) 224-4984	*>60':*	2	*>60':*	1		

Half Moon Anchorage:	*Powerboats:*	48	*Sailboats:*	135	*Range:*	20' - 60'+
Number of Slips: 183	*20' to 29':*	10	*20' to 29':*	60		
2131 Shelter Island Drive	*30' to 39':*	19	*30' to 39':*	50		
San Diego, Ca 92106	*40' to 49':*	11	*40' to 49':*	21		
Phone: (619) 222-0314	*50' to 59':*	3	*50' to 59':*	4		
Fax: (619) 224-4984	*>60':*	5	*>60':*	0		

San Diego Yacht Club:	*Powerboats:*	230	*Sailboats:*	346	*Range:*	20' - 60'+
Number of Slips: 576	*20' to 29':*	21	*20' to 29':*	41		
1011 Anchorage Lane	*30' to 39':*	101	*30' to 39':*	158		
San Diego, Ca 92106	*40' to 49':*	86	*40' to 49':*	133		
Phone: (619) 758-6308	*50' to 59':*	14	*50' to 59':*	14		
Fax: (619) 758-6338	*>60':*	8	*>60':*	0		
Cell: (619) 884-6309						
E-mail: brad@sdyc.org						

Shelter Cove Marina:	*Powerboats:*	30	*Sailboats:*	130	*Range:*	20' - 49'
Number of Slips: 160	*20' to 29':*	7	*20' to 29':*	9		
2240 Shelter Island Drive	*30' to 39':*	22	*30' to 39':*	13		
San Diego, Ca 92106	*40' to 49':*	1	*40' to 49':*	108		
Phone: (619) 224-2471	*50' to 59':*	0	*50' to 59':*	0		
Fax: (619) 224-9117	*>60':*	0	*>60':*	0		

Shelter Island Marina:	*Powerboats:*	51	*Sailboats:*	118	*Range:*	20' - 49'
*Number of Slips:*169	*20' to 29':*	20	*20' to 29':*	0		
2071 Shelter Island Drive	*30' to 39':*	11	*30' to 39':*	15		
San Diego, Ca 92106	*40' to 49':*	20	*40' to 49':*	103		
Phone: (619) 223-0301	*50' to 59':*	0	*50' to 59':*	0		
Fax: (619) 223-2113	*>60':*	0	*>60':*	0		

Shelter Pointe Hotel and Marina:	**(Marina Kona Kai)**					
Number of Slips: 523	*Powerboats:*	236	*Sailboats:*	287	*Range:*	24' - 100'
1551 Shelter Island Drive	*20' to 29':*	10	*20' to 29':*	15		

San Diego, Ca 92106	*30' to 39':*	137	*30' to 39':*	100		
Phone: (619) 224-7547	*40' to 49':*	70	*40' to 49':*	160		
Fax: (619) 222-0233	*50' to 59':*	10	*50' to 59':*	7		
Cell: (619) 994-5662	*>60':*	9	*>60':*	5		

Silver Gate Yacht Club:	*Powerboats:*	22	*Sailboats:*	128	*Range:*	20' - 59'
Number of Slips: 150	*20' to 29':*	4	*20' to 29':*	35		
2091 Shelter Island Drive	*30' to 39':*	16	*30' to 39':*	75		
San Diego, Ca 92106	*40' to 49':*	2	*40' to 49':*	15		
Phone: (619) 222-1214	*50' to 59':*	0	*50' to 59':*	3		
	>60':	0	*>60':*	0		
Southwestern Yacht Club:	*Powerboats:*	125	*Sailboats:*	246	*Range:*	20' - 60'+
Number of Slips: 382	*20' to 29':*	21	*20' to 29':*	50		
2702 Qualtrough Street	*30' to 39':*	46	*30' to 39':*	137		
San Diego, Ca 92106	*40' to 49':*	39	*40' to 49':*	52		
Phone: (619) 222-0438	*50' to 59':*	15	*50' to 59':*	5		
Fax: (619) 222-8214	*>60':*	4	*>60':*	2		
Sun Harbor Marina:	*Powerboats:*	42	*Sailboats:*	78	*Range:*	20' - 49'
Number of Slips: 120	*20' to 29':*	14	*20' to 29':*	26		
5104 North Harbor Drive	*30' to 39':*	14	*30' to 39':*	26		
San Diego, Ca 92106	*40' to 49':*	14	*40' to 49':*	26		
Phone: (619) 222-1167	*50' to 59':*	0	*50' to 59':*	0		
Fax: (619) 222-9387	*>60':*	0	*>60':*	0		

Moorings:

San Diego Mooring Co.	*Powerboats:*	131	*Sailboats:*	306	*Range:*	19' - 65'
Number of Moorings: 437	*20' to 29':*	33	*20' to 29':*	77		
2040 Harbor Island Drive Ste B116	*30' to 39':*	39	*30' to 39':*	92		
San Diego, Ca 92101	*40' to 49':*	33	*40' to 49':*	77		
Phone: (619) 291-0916	*50' to 59':*	20	*50' to 59':*	46		
Fax: (619) 291-2684	*>60':*	6	*>60':*	14		

Appendix A3: San Diego County Boatyards

San Diego Bay

Driscoll Boatworks
2500 Shelter Island Drive
San Diego 92106
(619) 226-2500

Knight & Carver, Inc.
1313 Bay Marina Drive
National City 91950
(619) 336-4141

Koehler Kraft
2302 Shelter Island Dr.
San Diego, Ca 92106
(619) 222-9051

Nielsen Beaumont Marine
2242 Shelter Island Drive
San Diego 92106
(619) 222-4255

Shelter Island Boatyard
2330 Shelter Island Drive
San Diego 92106
(619) 222-0481

South Bay Boatyard
997 "G" Street
Chula Vista
(619) 427-6767

Outside of San Diego Bay

Driscoll Mission Bay
1500 Quivera Way
San Diego 92109
(619) 223-5191

Oceanside Marine Center
1550 Harbor Drive North
Oceanside 92054
(760) 722-1833

Dana Point Shipyard
34671 Puerto Place
Dana Point 92629
(949) 661-1313

APPENDIX B: CHARACTERISTICS OF HULL COATINGS FORMALLY CONSIDERED

Paint Type	Product	VOC	# Coats to Apply	Total gallons needed	# Labor Hours	Application Frequency	Hull Cleaning Frequency
High Copper (66.9%)	Proline 1088	310g/l	2	4	N/A	2-3 years	Depends on Boat Use (see UWHC sheet for high copper paints)
High Copper (66.5%)	Interlux Ultra Kote	<330g/l	1	0.88	N/A	Each year	Owner's decision (again see UWHC sheet for high copper paints)
Low Copper (45.7%)	Pettit Unepoxy VOC	<330g/l	2	2	2 (for painting only)	Each year	As needed (see UWHC sheets)
Low Copper (37%)	Interlux Fiberglass Bottomkote Aqua	<150 g/l	2-3	2-2.5	N/A	Each year	As needed
Low Copper (40%)	Z*Spar Hydrocoat	<150 g/l	2	2	3 (for painting only)	Each year	As needed
Low Copper (26.37%)	Flexdel Aquaguard	133 g/l	2	3	6	2 years	Unknown
Epoxy*	AquaPly M	0	2	4	4	Once*	Every 2-3 weeks in warm water
Epoxy*	CeramKote	196 g/l	2	3	1.5	Every 5-10 years*	2 weeks summer and 3 weeks winter
Silicone	Water Shield (Miracle Cover)	0	1	2.5	1	3-5 years	Based on need (see UWHC sheets)
Silicone	Interlux Veridian Tiecoat-Primer	336 g/l	1	1.5	N/A	Depends on too many factors	Semi-monthly
Silicone	Interlux Veridian Topcoat	219 g/l	1	1.5	N/A	Every 2-3 years	Semi-monthly

Source: Paint Manufacturers/Retail stores
*Epoxy type paint manufactures and a San Diego boatyard have claimed a ten-year plus life span for epoxy coatings.

APPENDIX C: DESCRIPTION OF COST CALCULATONS

The calculations for determining costs of ownership for different paints were performed in Microsoft Excel. A model was built in Excel which calculates each period's maintenance costs based on changeable assumptions of paint characteristics and prices. These costs were then discounted and summed accordingly, depending on the relevant horizon and discount rate.

All calculations were made in discrete time, where each discrete period is six months in duration.

Cost of Ownership Calculations for Various Horizons

Each period's total cost consists of a cleaning cost, a painting cost, and a stripping cost. These costs vary according to assumptions regarding cleaning/painting/stripping frequencies and costs. These three costs are totaled in each separate period to obtain an undiscounted period cost of ownership.

In this model, cleaning costs are paid in the beginning of each period. Since most boaters enter into contracts with hull cleaners, the cleaning cost is often paid or at least agreed upon in advance of a six month period. Paint costs, on the other hand, are paid at the end of each period. The interpretation for this lies in the fact that paint is not actually worn out until the end of the period. For example, if a copper paint lasts 2.5 years, it does not need to be reapplied until the end of period 5. Therefore, a period's total cost is calculated as follows, where Cost(T) denotes the total amount paid at the start of period T.

$$\text{Cost}(T) = \text{Cleaning Cost}(T) + \text{Stripping Cost}(T-1) + \text{Cleaning Cost}(T-1)$$

To calculate cost of ownership figures for various horizons, these period costs are discounted and summed over the horizons of interest. For each period T, the discounted cost of ownership over a horizon of X years is obtained with the following formula, where r denotes the time discount rate:

$$\text{X-Year Cost of Ownership}(T) = \text{Cost}(T) + \frac{\text{Cost}(T+1)}{1/(1+r)} + \frac{\text{Cost}(T+2)}{[1/(1+r)]^2} + \ldots + \frac{\text{Cost}(T+X-1)}{[1/(1+r)]^{X-1}}$$

Boat Painted With Copper

To calculate the cost of ownership for copper boats at different stages of the boat's lifecycle, the x-year cost of ownership formula is evaluated at the appropriate periods. These periods are as follows:

New Boat:	X-Year Cost of Ownership(0)
Boat First Painted 2.5 Years Ago:	X-Year Cost of Ownership(5)
Boat First Painted 12.5 Years Ago:	X-Year Cost of Ownership(25)
Boat Stripped Today:	X-Year Cost of Ownership[(stripping frequency)*2]

Boat Painted With Epoxy

When considering the cost of ownership of an epoxy hull, it is assumed that a complete stripping is necessary in the first period unless the boat is new. Therefore, the cost of ownership at different lifecycle stages must be treated differently for the epoxy boat than for the copper boat.

For a new boat, the calculation remains as it was for copper since no stripping is necessary if epoxy is the first paint ever applied to the hull. However, for boats at other stages, the cost of ownership will always consist of a stripping in the first period, and will then begin at the start of a stripping cycle. Therefore, regardless of when the boat was first painted or when it was last stripped, the x-year cost of ownership of an epoxy hull will always be the same—it will equal the x-year cost of ownership of a new boat plus a stripping cost.

To summarize, the cost of ownership for epoxy boats at different stages of the boat's lifecycle is obtained by evaluating the following formulas, all at period 0:

New Boat:	X-Year Cost of Ownership(0)
Boat Previously Painted:	X-Year Cost of Ownership(0)+stripping cost

Methodology in Microsoft Excel

Figure A-1 provides an example of a spreadsheet used for this model. This example calculates the one-year cost of ownership of a boat painted with copper bottom paint, where the assumptions about the boat and its paint's characteristics are shown at the top of the figure. In Excel, one can change the assumptions in these cells, and the calculations which are triggered to these assumptions will change accordingly. Figure A-2 shows this same spreadsheet with the underlying formulas in each cell, rather than the calculated values.

The calculations in these spreadsheets can be understood as follows:

1) *Cleaning Costs*: The number of cleanings required in each 6-month period is a simple calculation dividing the annual number of cleanings required by two. Then, the cleaning cost per period is obtained by:

cleaning cost = (number of cleanings)*(cleaning cost per foot)*(boat size)

2) *Painting Costs*: To obtain the number of paintings required in each six month period (which will always be either 1 or 0), the "mod" and "if" functions of Excel are used. The mod function returns a remainder after a number is divided by a given divisor. Therefore, one can evaluate the following:

if mod(period,(painting frequency*2)) = 0, then number of paintings = 1
if mod(period,(painting frequency*2)) > 0, then number of paintings = 0

When evaluated this way, whether or not a painting is required in a certain period is automatically linked to the assumption of required painting frequency. Then, the number of paintings in each period is multiplied by the painting cost as follows, to obtain each period's painting cost.

painting cost = (number of paintings)*(painting cost per foot)*(boat size)

3) *Stripping Costs*: The methodology for modeling when strippings occur and what their costs are in each period is exactly the same as for painting costs. The "mod" and "if" functions are employed and the stripping cost is calculated:

stripping cost = (number of strippings)*(stripping cost per foot)*(boat size),

where in the time periods considered stripping is either 0 or 1 and only done once during the life of the boat.

4) *Discounting*: The discount factor is calculated with the simple formula:

$$\text{discount factor} = 1/(1-r)^T$$

It should be noted that, when discounting a series of costs, the first X periods of the discount factor were fixed by using the "$" feature in Excel. For example, when discounting costs from period 30 through 34 (as when calculating the 2.5 year cost of ownership for a copper boat stripped today), the discount factors for periods 0 through 4 were used so as to simulate starting in period 30 today.

FIGURE C-1: EXAMPLE OF CALCULATION SPREADSHEET
(Costs of Ownership - Boat Painted with Copper at Time 0)

ASSUMPTIONS

Boat Size	40	ft.
Disc. Rate	5%	

Cleaning Costs

Paint	Cost (per ft)	Frequency (per year)
High Cu	1	14
Epoxy	1	22

Painting Costs

Paint	Cost (per ft)	Freq. (every _ yrs)
High Cu	30	2.5
Epoxy	50	10
Stripping	150	15

Period	# of Cleanings	Cleaning Cost	# of Paintings	Paint Cost	# of Strippings	Stripping Cost	Total Cost	Discount Factor	1 Year Cost of Ownership: Copper Hull
0	7	280	1	1,200	0	0	1,480	1.00	1,746
1	7	280	0	0	0	0	280	1.05	546
2	7	280	0	0	0	0	280	1.11	546
3	7	280	0	0	0	0	280	1.17	546
4	7	280	0	0	0	0	280	1.23	1,686
5	7	280	1	1,200	0	0	1,480	1.29	1,746
6	7	280	0	0	0	0	280	1.36	546
7	7	280	0	0	0	0	280	1.43	546
8	7	280	0	0	0	0	280	1.51	546
9	7	280	0	0	0	0	280	1.59	1,686
10	7	280	1	1,200	0	0	1,480	1.67	1,746
11	7	280	0	0	0	0	280	1.76	546
12	7	280	0	0	0	0	280	1.85	546
13	7	280	0	0	0	0	280	1.95	546
14	7	280	0	0	0	0	280	2.05	1,686
15	7	280	1	1,200	0	0	1,480	2.16	1,746
16	7	280	0	0	0	0	280	2.27	546
17	7	280	0	0	0	0	280	2.39	546
18	7	280	0	0	0	0	280	2.52	546
19	7	280	0	0	0	0	280	2.65	1,686
20	7	280	1	1,200	0	0	1,480	2.79	1,746
21	7	280	0	0	0	0	280	2.94	546
22	7	280	0	0	0	0	280	3.09	546
23	7	280	0	0	0	0	280	3.25	546
24	7	280	0	0	0	0	280	3.42	1,686
25	7	280	1	1,200	0	0	1,480	3.61	1,746
26	7	280	0	0	0	0	280	3.79	546
27	7	280	0	0	0	0	280	3.99	546
28	7	280	0	0	0	0	280	4.20	546
29	7	280	0	0	0	0	280	4.43	7,386
30	7	280	1	1,200	1	6,000	7,480	4.66	7,746
31	7	280	0	0	0	0	280	4.90	546
32	7	280	0	0	0	0	280	5.16	546
33	7	280	0	0	0	0	280	5.43	546
34	7	280	0	0	0	0	280	5.72	1,686
35	7	280	1	1,200	0	0	1,480	6.02	1,746
36	7	280	0	0	0	0	280	6.34	546
37	7	280	0	0	0	0	280	6.67	546
38	7	280	0	0	0	0	280	7.02	546
39	7	280	0	0	0	0	280	7.39	1,686
40	7	280	1	1,200	0	0	1,480	7.78	1,746
41	7	280	0	0	0	0	280	8.19	546
42	7	280	0	0	0	0	280	8.62	546
43	7	280	0	0	0	0	280	9.08	546
44	7	280	0	0	0	0	280	9.55	1,686
45	7	280	1	1,200	0	0	1,480	10.06	1,746
46	7	280	0	0	0	0	280	10.59	546
47	7	280	0	0	0	0	280	11.14	546
48	7	280	0	0	0	0	280	11.73	546
49	7	280	0	0	0	0	280	12.35	1,686
50	7	280	1	1,200	0	0	1,480	13.00	1,746
51	7	280	0	0	0	0	280	13.68	546
52	7	280	0	0	0	0	280	14.40	546
53	7	280	0	0	0	0	280	15.16	546
54	7	280	0	0	0	0	280	15.96	1,686
55	7	280	1	1,200	0	0	1,480	16.80	1,746
56	7	280	0	0	0	0	280	17.68	546
57	7	280	0	0	0	0	280	18.61	546
58	7	280	0	0	0	0	280	19.59	546
59	7	280	0	0	0	0	280	20.62	7,386
60	7	280	1	1,200	1	6,000	7,480	21.71	7,746

FIGURE C-2: EXAMPLE OF UNDERLYING EXCEL FORMULAS COSTS OF OWNERSHIP - BOAT PAINTED WITH COPPER AT TIME 0

Period	# of Cleanings	Cleaning Cost	# of Paintings	Paint Cost	# of Strippings	Stripping Cost	Total Cost	Discount Factor	1 Year Cost of Ownership: Copper Hull
0	=$C$8/2	=B15*$B$8*$B$2	=IF(MOD(A15,$G$8*2)<1,1,0)	=D15*$F$8*$B$2	0	=$F15*$F$10*$B$2	=G15+E15+C15	=1/((1-$B$3)^($A15))	=$H15/$I$15+$H16/$I$16
1	=$C$8/2	=B16*$B$8*$B$2	=IF(MOD(A16,$G$8*2)<1,1,0)	=D16*$F$8*$B$2	=IF(MOD($A16,$G$10*2)<1,1,0)	=$F16*$F$10*$B$2	=G16+E16+C16	=1/((1-$B$3)^($A16))	=$H16/$I$15+$H17/$I$16
2	=$C$8/2	=B17*$B$8*$B$2	=IF(MOD(A17,$G$8*2)<1,1,0)	=D17*$F$8*$B$2	=IF(MOD($A17,$G$10*2)<1,1,0)	=$F17*$F$10*$B$2	=G17+E17+C17	=1/((1-$B$3)^($A17))	=$H17/$I$15+$H18/$I$16
3	=$C$8/2	=B18*$B$8*$B$2	=IF(MOD(A18,$G$8*2)<1,1,0)	=D18*$F$8*$B$2	=IF(MOD($A18,$G$10*2)<1,1,0)	=$F18*$F$10*$B$2	=G18+E18+C18	=1/((1-$B$3)^($A18))	=$H18/$I$15+$H19/$I$16
4	=$C$8/2	=B19*$B$8*$B$2	=IF(MOD(A19,$G$8*2)<1,1,0)	=D19*$F$8*$B$2	=IF(MOD($A19,$G$10*2)<1,1,0)	=$F19*$F$10*$B$2	=G19+E19+C19	=1/((1-$B$3)^($A19))	=$H19/$I$15+$H20/$I$16
5	=$C$8/2	=B20*$B$8*$B$2	=IF(MOD(A20,$G$8*2)<1,1,0)	=D20*$F$8*$B$2	=IF(MOD($A20,$G$10*2)<1,1,0)	=$F20*$F$10*$B$2	=G20+E20+C20	=1/((1-$B$3)^($A20))	=$H20/$I$15+$H21/$I$16
6	=$C$8/2	=B21*$B$8*$B$2	=IF(MOD(A21,$G$8*2)<1,1,0)	=D21*$F$8*$B$2	=IF(MOD($A21,$G$10*2)<1,1,0)	=$F21*$F$10*$B$2	=G21+E21+C21	=1/((1-$B$3)^($A21))	=$H21/$I$15+$H22/$I$16
7	=$C$8/2	=B22*$B$8*$B$2	=IF(MOD(A22,$G$8*2)<1,1,0)	=D22*$F$8*$B$2	=IF(MOD($A22,$G$10*2)<1,1,0)	=$F22*$F$10*$B$2	=G22+E22+C22	=1/((1-$B$3)^($A22))	=$H22/$I$15+$H23/$I$16
8	=$C$8/2	=B23*$B$8*$B$2	=IF(MOD(A23,$G$8*2)<1,1,0)	=D23*$F$8*$B$2	=IF(MOD($A23,$G$10*2)<1,1,0)	=$F23*$F$10*$B$2	=G23+E23+C23	=1/((1-$B$3)^($A23))	=$H23/$I$15+$H24/$I$16
9	=$C$8/2	=B24*$B$8*$B$2	=IF(MOD(A24,$G$8*2)<1,1,0)	=D24*$F$8*$B$2	=IF(MOD($A24,$G$10*2)<1,1,0)	=$F24*$F$10*$B$2	=G24+E24+C24	=1/((1-$B$3)^($A24))	=$H24/$I$15+$H25/$I$16
10	=$C$8/2	=B25*$B$8*$B$2	=IF(MOD(A25,$G$8*2)<1,1,0)	=D25*$F$8*$B$2	=IF(MOD($A25,$G$10*2)<1,1,0)	=$F25*$F$10*$B$2	=G25+E25+C25	=1/((1-$B$3)^($A25))	=$H25/$I$15+$H26/$I$16
11	=$C$8/2	=B26*$B$8*$B$2	=IF(MOD(A26,$G$8*2)<1,1,0)	=D26*$F$8*$B$2	=IF(MOD($A26,$G$10*2)<1,1,0)	=$F26*$F$10*$B$2	=G26+E26+C26	=1/((1-$B$3)^($A26))	=$H26/$I$15+$H27/$I$16
12	=$C$8/2	=B27*$B$8*$B$2	=IF(MOD(A27,$G$8*2)<1,1,0)	=D27*$F$8*$B$2	=IF(MOD($A27,$G$10*2)<1,1,0)	=$F27*$F$10*$B$2	=G27+E27+C27	=1/((1-$B$3)^($A27))	=$H27/$I$15+$H28/$I$16
13	=$C$8/2	=B28*$B$8*$B$2	=IF(MOD(A28,$G$8*2)<1,1,0)	=D28*$F$8*$B$2	=IF(MOD($A28,$G$10*2)<1,1,0)	=$F28*$F$10*$B$2	=G28+E28+C28	=1/((1-$B$3)^($A28))	=$H28/$I$15+$H29/$I$16
14	=$C$8/2	=B29*$B$8*$B$2	=IF(MOD(A29,$G$8*2)<1,1,0)	=D29*$F$8*$B$2	=IF(MOD($A29,$G$10*2)<1,1,0)	=$F29*$F$10*$B$2	=G29+E29+C29	=1/((1-$B$3)^($A29))	=$H29/$I$15+$H30/$I$16
15	=$C$8/2	=B30*$B$8*$B$2	=IF(MOD(A30,$G$8*2)<1,1,0)	=D30*$F$8*$B$2	=IF(MOD($A30,$G$10*2)<1,1,0)	=$F30*$F$10*$B$2	=G30+E30+C30	=1/((1-$B$3)^($A30))	=$H30/$I$15+$H31/$I$16
16	=$C$8/2	=B31*$B$8*$B$2	=IF(MOD(A31,$G$8*2)<1,1,0)	=D31*$F$8*$B$2	=IF(MOD($A31,$G$10*2)<1,1,0)	=$F31*$F$10*$B$2	=G31+E31+C31	=1/((1-$B$3)^($A31))	=$H31/$I$15+$H32/$I$16
17	=$C$8/2	=B32*$B$8*$B$2	=IF(MOD(A32,$G$8*2)<1,1,0)	=D32*$F$8*$B$2	=IF(MOD($A32,$G$10*2)<1,1,0)	=$F32*$F$10*$B$2	=G32+E32+C32	=1/((1-$B$3)^($A32))	=$H32/$I$15+$H33/$I$16
18	=$C$8/2	=B33*$B$8*$B$2	=IF(MOD(A33,$G$8*2)<1,1,0)	=D33*$F$8*$B$2	=IF(MOD($A33,$G$10*2)<1,1,0)	=$F33*$F$10*$B$2	=G33+E33+C33	=1/((1-$B$3)^($A33))	=$H33/$I$15+$H34/$I$16
19	=$C$8/2	=B34*$B$8*$B$2	=IF(MOD(A34,$G$8*2)<1,1,0)	=D34*$F$8*$B$2	=IF(MOD($A34,$G$10*2)<1,1,0)	=$F34*$F$10*$B$2	=G34+E34+C34	=1/((1-$B$3)^($A34))	=$H34/$I$15+$H35/$I$16
20	=$C$8/2	=B35*$B$8*$B$2	=IF(MOD(A35,$G$8*2)<1,1,0)	=D35*$F$8*$B$2	=IF(MOD($A35,$G$10*2)<1,1,0)	=$F35*$F$10*$B$2	=G35+E35+C35	=1/((1-$B$3)^($A35))	=$H35/$I$15+$H36/$I$16
21	=$C$8/2	=B36*$B$8*$B$2	=IF(MOD(A36,$G$8*2)<1,1,0)	=D36*$F$8*$B$2	=IF(MOD($A36,$G$10*2)<1,1,0)	=$F36*$F$10*$B$2	=G36+E36+C36	=1/((1-$B$3)^($A36))	=$H36/$I$15+$H37/$I$16
22	=$C$8/2	=B37*$B$8*$B$2	=IF(MOD(A37,$G$8*2)<1,1,0)	=D37*$F$8*$B$2	=IF(MOD($A37,$G$10*2)<1,1,0)	=$F37*$F$10*$B$2	=G37+E37+C37	=1/((1-$B$3)^($A37))	=$H37/$I$15+$H38/$I$16
23	=$C$8/2	=B38*$B$8*$B$2	=IF(MOD(A38,$G$8*2)<1,1,0)	=D38*$F$8*$B$2	=IF(MOD($A38,$G$10*2)<1,1,0)	=$F38*$F$10*$B$2	=G38+E38+C38	=1/((1-$B$3)^($A38))	=$H38/$I$15+$H39/$I$16
24	=$C$8/2	=B39*$B$8*$B$2	=IF(MOD(A39,$G$8*2)<1,1,0)	=D39*$F$8*$B$2	=IF(MOD($A39,$G$10*2)<1,1,0)	=$F39*$F$10*$B$2	=G39+E39+C39	=1/((1-$B$3)^($A39))	=$H39/$I$15+$H40/$I$16
25	=$C$8/2	=B40*$B$8*$B$2	=IF(MOD(A40,$G$8*2)<1,1,0)	=D40*$F$8*$B$2	=IF(MOD($A40,$G$10*2)<1,1,0)	=$F40*$F$10*$B$2	=G40+E40+C40	=1/((1-$B$3)^($A40))	=$H40/$I$15+$H41/$I$16
26	=$C$8/2	=B41*$B$8*$B$2	=IF(MOD(A41,$G$8*2)<1,1,0)	=D41*$F$8*$B$2	=IF(MOD($A41,$G$10*2)<1,1,0)	=$F41*$F$10*$B$2	=G41+E41+C41	=1/((1-$B$3)^($A41))	=$H41/$I$15+$H42/$I$16
27	=$C$8/2	=B42*$B$8*$B$2	=IF(MOD(A42,$G$8*2)<1,1,0)	=D42*$F$8*$B$2	=IF(MOD($A42,$G$10*2)<1,1,0)	=$F42*$F$10*$B$2	=G42+E42+C42	=1/((1-$B$3)^($A42))	=$H42/$I$15+$H43/$I$16
28	=$C$8/2	=B43*$B$8*$B$2	=IF(MOD(A43,$G$8*2)<1,1,0)	=D43*$F$8*$B$2	=IF(MOD($A43,$G$10*2)<1,1,0)	=$F43*$F$10*$B$2	=G43+E43+C43	=1/((1-$B$3)^($A43))	=$H43/$I$15+$H44/$I$16
29	=$C$8/2	=B44*$B$8*$B$2	=IF(MOD(A44,$G$8*2)<1,1,0)	=D44*$F$8*$B$2	=IF(MOD($A44,$G$10*2)<1,1,0)	=$F44*$F$10*$B$2	=G44+E44+C44	=1/((1-$B$3)^($A44))	=$H44/$I$15+$H45/$I$16
30	=$C$8/2	=B45*$B$8*$B$2	=IF(MOD(A45,$G$8*2)<1,1,0)	=D45*$F$8*$B$2	=IF(MOD($A45,$G$10*2)<1,1,0)	=$F45*$F$10*$B$2	=G45+E45+C45	=1/((1-$B$3)^($A45))	=$H45/$I$15+$H46/$I$16
31	=$C$8/2	=B46*$B$8*$B$2	=IF(MOD(A46,$G$8*2)<1,1,0)	=D46*$F$8*$B$2	=IF(MOD($A46,$G$10*2)<1,1,0)	=$F46*$F$10*$B$2	=G46+E46+C46	=1/((1-$B$3)^($A46))	=$H46/$I$15+$H47/$I$16
32	=$C$8/2	=B47*$B$8*$B$2	=IF(MOD(A47,$G$8*2)<1,1,0)	=D47*$F$8*$B$2	=IF(MOD($A47,$G$10*2)<1,1,0)	=$F47*$F$10*$B$2	=G47+E47+C47	=1/((1-$B$3)^($A47))	=$H47/$I$15+$H48/$I$16
33	=$C$8/2	=B48*$B$8*$B$2	=IF(MOD(A48,$G$8*2)<1,1,0)	=D48*$F$8*$B$2	=IF(MOD($A48,$G$10*2)<1,1,0)	=$F48*$F$10*$B$2	=G48+E48+C48	=1/((1-$B$3)^($A48))	=$H48/$I$15+$H49/$I$16
34	=$C$8/2	=B49*$B$8*$B$2	=IF(MOD(A49,$G$8*2)<1,1,0)	=D49*$F$8*$B$2	=IF(MOD($A49,$G$10*2)<1,1,0)	=$F49*$F$10*$B$2	=G49+E49+C49	=1/((1-$B$3)^($A49))	=$H49/$I$15+$H50/$I$16
35	=$C$8/2	=B50*$B$8*$B$2	=IF(MOD(A50,$G$8*2)<1,1,0)	=D50*$F$8*$B$2	=IF(MOD($A50,$G$10*2)<1,1,0)	=$F50*$F$10*$B$2	=G50+E50+C50	=1/((1-$B$3)^($A50))	=$H50/$I$15+$H51/$I$16
36	=$C$8/2	=B51*$B$8*$B$2	=IF(MOD(A51,$G$8*2)<1,1,0)	=D51*$F$8*$B$2	=IF(MOD($A51,$G$10*2)<1,1,0)	=$F51*$F$10*$B$2	=G51+E51+C51	=1/((1-$B$3)^($A51))	=$H51/$I$15+$H52/$I$16
37	=$C$8/2	=B52*$B$8*$B$2	=IF(MOD(A52,$G$8*2)<1,1,0)	=D52*$F$8*$B$2	=IF(MOD($A52,$G$10*2)<1,1,0)	=$F52*$F$10*$B$2	=G52+E52+C52	=1/((1-$B$3)^($A52))	=$H52/$I$15+$H53/$I$16
38	=$C$8/2	=B53*$B$8*$B$2	=IF(MOD(A53,$G$8*2)<1,1,0)	=D53*$F$8*$B$2	=IF(MOD($A53,$G$10*2)<1,1,0)	=$F53*$F$10*$B$2	=G53+E53+C53	=1/((1-$B$3)^($A53))	=$H53/$I$15+$H54/$I$16
39	=$C$8/2	=B54*$B$8*$B$2	=IF(MOD(A54,$G$8*2)<1,1,0)	=D54*$F$8*$B$2	=IF(MOD($A54,$G$10*2)<1,1,0)	=$F54*$F$10*$B$2	=G54+E54+C54	=1/((1-$B$3)^($A54))	=$H54/$I$15+$H55/$I$16
40	=$C$8/2	=B55*$B$8*$B$2	=IF(MOD(A55,$G$8*2)<1,1,0)	=D55*$F$8*$B$2	=IF(MOD($A55,$G$10*2)<1,1,0)	=$F55*$F$10*$B$2	=G55+E55+C55	=1/((1-$B$3)^($A55))	=$H55/$I$15+$H56/$I$16
41	=$C$8/2	=B56*$B$8*$B$2	=IF(MOD(A56,$G$8*2)<1,1,0)	=D56*$F$8*$B$2	=IF(MOD($A56,$G$10*2)<1,1,0)	=$F56*$F$10*$B$2	=G56+E56+C56	=1/((1-$B$3)^($A56))	=$H56/$I$15+$H57/$I$16
42	=$C$8/2	=B57*$B$8*$B$2	=IF(MOD(A57,$G$8*2)<1,1,0)	=D57*$F$8*$B$2	=IF(MOD($A57,$G$10*2)<1,1,0)	=$F57*$F$10*$B$2	=G57+E57+C57	=1/((1-$B$3)^($A57))	=$H57/$I$15+$H58/$I$16
43	=$C$8/2	=B58*$B$8*$B$2	=IF(MOD(A58,$G$8*2)<1,1,0)	=D58*$F$8*$B$2	=IF(MOD($A58,$G$10*2)<1,1,0)	=$F58*$F$10*$B$2	=G58+E58+C58	=1/((1-$B$3)^($A58))	=$H58/$I$15+$H59/$I$16
44	=$C$8/2	=B59*$B$8*$B$2	=IF(MOD(A59,$G$8*2)<1,1,0)	=D59*$F$8*$B$2	=IF(MOD($A59,$G$10*2)<1,1,0)	=$F59*$F$10*$B$2	=G59+E59+C59	=1/((1-$B$3)^($A59))	=$H59/$I$15+$H60/$I$16
45	=$C$8/2	=B60*$B$8*$B$2	=IF(MOD(A60,$G$8*2)<1,1,0)	=D60*$F$8*$B$2	=IF(MOD($A60,$G$10*2)<1,1,0)	=$F60*$F$10*$B$2	=G60+E60+C60	=1/((1-$B$3)^($A60))	=$H60/$I$15+$H61/$I$16
46	=$C$8/2	=B61*$B$8*$B$2	=IF(MOD(A61,$G$8*2)<1,1,0)	=D61*$F$8*$B$2	=IF(MOD($A61,$G$10*2)<1,1,0)	=$F61*$F$10*$B$2	=G61+E61+C61	=1/((1-$B$3)^($A61))	=$H61/$I$15+$H62/$I$16
47	=$C$8/2	=B62*$B$8*$B$2	=IF(MOD(A62,$G$8*2)<1,1,0)	=D62*$F$8*$B$2	=IF(MOD($A62,$G$10*2)<1,1,0)	=$F62*$F$10*$B$2	=G62+E62+C62	=1/((1-$B$3)^($A62))	=$H62/$I$15+$H63/$I$16
48	=$C$8/2	=B63*$B$8*$B$2	=IF(MOD(A63,$G$8*2)<1,1,0)	=D63*$F$8*$B$2	=IF(MOD($A63,$G$10*2)<1,1,0)	=$F63*$F$10*$B$2	=G63+E63+C63	=1/((1-$B$3)^($A63))	=$H63/$I$15+$H64/$I$16
49	=$C$8/2	=B64*$B$8*$B$2	=IF(MOD(A64,$G$8*2)<1,1,0)	=D64*$F$8*$B$2	=IF(MOD($A64,$G$10*2)<1,1,0)	=$F64*$F$10*$B$2	=G64+E64+C64	=1/((1-$B$3)^($A64))	=$H64/$I$15+$H65/$I$16
50	=$C$8/2	=B65*$B$8*$B$2	=IF(MOD(A65,$G$8*2)<1,1,0)	=D65*$F$8*$B$2	=IF(MOD($A65,$G$10*2)<1,1,0)	=$F65*$F$10*$B$2	=G65+E65+C65	=1/((1-$B$3)^($A65))	=$H65/$I$15+$H66/$I$16
51	=$C$8/2	=B66*$B$8*$B$2	=IF(MOD(A66,$G$8*2)<1,1,0)	=D66*$F$8*$B$2	=IF(MOD($A66,$G$10*2)<1,1,0)	=$F66*$F$10*$B$2	=G66+E66+C66	=1/((1-$B$3)^($A66))	=$H66/$I$15+$H67/$I$16
52	=$C$8/2	=B67*$B$8*$B$2	=IF(MOD(A67,$G$8*2)<1,1,0)	=D67*$F$8*$B$2	=IF(MOD($A67,$G$10*2)<1,1,0)	=$F67*$F$10*$B$2	=G67+E67+C67	=1/((1-$B$3)^($A67))	=$H67/$I$15+$H68/$I$16
53	=$C$8/2	=B68*$B$8*$B$2	=IF(MOD(A68,$G$8*2)<1,1,0)	=D68*$F$8*$B$2	=IF(MOD($A68,$G$10*2)<1,1,0)	=$F68*$F$10*$B$2	=G68+E68+C68	=1/((1-$B$3)^($A68))	=$H68/$I$15+$H69/$I$16
54	=$C$8/2	=B69*$B$8*$B$2	=IF(MOD(A69,$G$8*2)<1,1,0)	=D69*$F$8*$B$2	=IF(MOD($A69,$G$10*2)<1,1,0)	=$F69*$F$10*$B$2	=G69+E69+C69	=1/((1-$B$3)^($A69))	=$H69/$I$15+$H70/$I$16
55	=$C$8/2	=B70*$B$8*$B$2	=IF(MOD(A70,$G$8*2)<1,1,0)	=D70*$F$8*$B$2	=IF(MOD($A70,$G$10*2)<1,1,0)	=$F70*$F$10*$B$2	=G70+E70+C70	=1/((1-$B$3)^($A70))	=$H70/$I$15+$H71/$I$16
56	=$C$8/2	=B71*$B$8*$B$2	=IF(MOD(A71,$G$8*2)<1,1,0)	=D71*$F$8*$B$2	=IF(MOD($A71,$G$10*2)<1,1,0)	=$F71*$F$10*$B$2	=G71+E71+C71	=1/((1-$B$3)^($A71))	=$H71/$I$15+$H72/$I$16
57	=$C$8/2	=B72*$B$8*$B$2	=IF(MOD(A72,$G$8*2)<1,1,0)	=D72*$F$8*$B$2	=IF(MOD($A72,$G$10*2)<1,1,0)	=$F72*$F$10*$B$2	=G72+E72+C72	=1/((1-$B$3)^($A72))	=$H72/$I$15+$H73/$I$16
58	=$C$8/2	=B73*$B$8*$B$2	=IF(MOD(A73,$G$8*2)<1,1,0)	=D73*$F$8*$B$2	=IF(MOD($A73,$G$10*2)<1,1,0)	=$F73*$F$10*$B$2	=G73+E73+C73	=1/((1-$B$3)^($A73))	=$H73/$I$15+$H74/$I$16
59	=$C$8/2	=B74*$B$8*$B$2	=IF(MOD(A74,$G$8*2)<1,1,0)	=D74*$F$8*$B$2	=IF(MOD($A74,$G$10*2)<1,1,0)	=$F74*$F$10*$B$2	=G74+E74+C74	=1/((1-$B$3)^($A74))	=$H74/$I$15+$H75/$I$16
60	=$C$8/2	=B75*$B$8*$B$2	=IF(MOD(A75,$G$8*2)<1,1,0)	=D75*$F$8*$B$2	=IF(MOD($A75,$G$10*2)<1,1,0)	=$F75*$F$10*$B$2	=G75+E75+C75	=1/((1-$B$3)^($A75))	=$H75/$I$15+$H76/$I$16

APPENDIX D: COST CALCULATONS

D1: COST CALCULATIONS FOR DIFFERENT AGED BOATS

Default Assumptions:
Discount Rate = 5%
Stripping cost: $120/ft
Cu cost: $30/ft; Cu duration: 2.5 years; Cu cleaning: 14 times/year
Epoxy cleaning: 22 times/year

Figure D1-A: 2.5 Year Old Boat (12.5 yrs until stripped, 27.5 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	27.5 Year Cost of Ownership: Copper Hull	27.5 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	30	12,060	16,350	4,290
5	40	12,060	17,331	5,271
5	50	12,060	18,312	6,251
7.5	30	12,060	15,597	3,537
7.5	40	12,060	16,327	4,266
7.5	50	12,060	17,056	4,996
10	30	12,060	15,231	3,171
10	40	12,060	15,839	3,779
10	50	12,060	16,447	4,386

Figure D1-B: 5 Year Old Boat (10 yrs until stripped, 25 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	25 Year Cost of Ownership: Copper Hull	25 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	30	12,236	16,071	3,835
5	40	12,236	17,017	4,781
5	50	12,236	17,963	5,726
7.5	30	12,236	15,423	3,186
7.5	40	12,236	16,152	3,916
7.5	50	12,236	16,882	4,645
10	30	12,236	15,057	2,821
10	40	12,236	15,665	3,428
10	50	12,236	16,272	4,036

Figure D1-C: 7.5 Year Old Boat (7.5 yrs until stripped, 22.5 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	22.5 Year Cost of Ownership: Copper Hull	22.5 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	30	12,461	15,849	3,388
5	40	12,461	16,794	4,333
5	50	12,461	17,740	5,279
7.5	30	12,461	15,066	2,606
7.5	40	12,461	15,751	3,291
7.5	50	12,461	16,436	3,976
10	30	12,461	14,834	2,373
10	40	12,461	15,442	2,981
10	50	12,461	16,049	3,589

Figure D1-D: 10 Year Old Boat (5 yrs until stripped, 20 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	20 Year Cost of Ownership: Copper Hull	20 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	30	12,748	15,394	2,647
5	40	12,748	16,283	3,535
5	50	12,748	17,172	4,424
7.5	30	12,748	14,782	2,035
7.5	40	12,748	15,467	2,720
7.5	50	12,748	16,152	3,405
10	30	12,748	14,380	1,632
10	40	12,748	14,931	2,183
10	50	12,748	15,481	2,734

Figure D1-E: 12.5 Year Old Boat (2.5 yrs until stripped, 17.5 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	17.5 Year Cost of Ownership: Copper Hull	17.5 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	30	13,113	15,031	1,918
5	40	13,113	15,920	2,807
5	50	13,113	16,809	3,696
7.5	30	13,113	14,420	1,306
7.5	40	13,113	15,105	1,991
7.5	50	13,113	15,790	2,676
10	30	13,113	14,017	904
10	40	13,113	14,568	1,455
10	50	13,113	15,119	2,005

Figure D1-F: 15 Year Old Boat (stripped today, 15 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	15 Year Cost of Ownership: Copper Hull	15 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	50	13,580	14,291	711
5	40	13,580	15,087	1,507
5	30	13,580	15,884	2,303
7.5	30	13,580	13,679	99
7.5	40	13,580	14,272	691
7.5	50	13,580	14,864	1,284
10	30	13,580	13,554	-26
10	40	13,580	14,105	525
10	50	13,580	14,656	1,076

Figure D1-G: 17.5 Year Old Boat (not stripped again, 12.5 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	12.5 Year Cost of Ownership: Copper Hull	12.5 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	50	8,050	13,700	5,650
5	40	8,050	14,497	6,447
5	30	8,050	15,293	7,243
7.5	30	8,050	13,089	5,039
7.5	40	8,050	13,681	5,631
7.5	50	8,050	14,273	6,223
10	30	8,050	12,964	4,914
10	40	8,050	13,514	5,464
10	50	8,050	14,065	6,015

Figure D1-H: 20 Year Old Boat (not stripped again, 10 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	10 Year Cost of Ownership: Copper Hull	10 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	50	7,118	12,494	5,376
5	40	7,118	13,140	6,022
5	30	7,118	13,785	6,667
7.5	30	7,118	12,335	5,217
7.5	40	7,118	12,927	5,809
7.5	50	7,118	13,520	6,402
10	30	7,118	11,758	4,640
10	40	7,118	12,158	5,040
10	50	7,118	12,558	5,440

Figure D1-I: 22.5 Year Old Boat (not stripped again, 7.5 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	7.5 Year Cost of Ownership: Copper Hull	7.5 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	50	5,929	11,532	5,604
5	40	5,929	12,178	6,249
5	30	5,929	12,823	6,895
7.5	30	5,929	10,795	4,867
7.5	40	5,929	11,195	5,267
7.5	50	5,929	11,595	5,667
10	30	5,929	10,795	4,867
10	40	5,929	11,195	5,267
10	50	5,929	11,595	5,667

Figure D1-J: 25 Year Old Boat (not stripped again, 5 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	5 Year Cost of Ownership: Copper Hull	5 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	50	4,410	9,567	5,157
5	40	4,410	9,967	5,557
5	30	4,410	10,367	5,957
7.5	50	4,410	9,567	5,157
7.5	40	4,410	9,967	5,557
7.5	30	4,410	10,367	5,957
10	50	4,410	9,567	5,157
10	40	4,410	9,967	5,557
10	30	4,410	10,367	5,957

Figure D1-K: 27.5 Year Old Boat (not stripped again, 2.5 yrs of service life left)

Epoxy Duration (yrs)	Cost of Epoxy ($/ft)	2.5 Year Cost of Ownership: Copper Hull	2.5 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
5	50	2,473	8,000	5,527
5	40	2,473	8,400	5,927
5	30	2,473	8,800	6,327
7.5	50	2,473	8,000	5,527
7.5	40	2,473	8,400	5,927
7.5	30	2,473	8,800	6,327
10	50	2,473	8,000	5,527
10	40	2,473	8,400	5,927
10	30	2,473	8,800	6,327

D2: NEW BOAT CALCULATIONS

Default Assumptions:
Discount Rate = 5%
Stripping cost: $120/ft
Cu cost: $30/ft; Cu duration: 2.5 years; Cu cleaning: 14 times/year
Epoxy cost: $40/ft; Epoxy duration: 7.5 years; Epoxy cleaning: 22 times/year

Figure D2-A: Comparison of Different Stripping Costs with Different Paint Costs

Cost of Epoxy ($/ft)	Cost of Stripping ($/ft)	30 Year Cost of Ownership: Copper Hull	30 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
30	120	11,922	10,934	-989
30	75	11,046	10,527	-519
40	120	11,922	11,663	-259
40	75	11,046	11,238	192
50	120	11,922	12,393	470
50	75	11,046	11,949	903

Figure D2-B: Comparison of Different Copper and Epoxy Prices

Cost of Copper ($/ft)	Cost of Epoxy ($/ft)	30 Year Cost of Ownership: Copper Hull	30 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
20	30	10,174	10,934	760
20	40	10,174	11,663	1,490
20	50	10,174	12,393	2,219
25	30	11,048	10,934	-114
25	40	11,048	11,663	615
25	50	11,048	12,393	1,345
30	30	11,922	10,934	-989
30	40	11,922	11,663	-259
30	50	11,922	12,393	470

Figure D2-C: Comparison of Different Copper and Epoxy Durations

Copper Duration (yrs)	Epoxy Duration (yrs)	30 Year Cost of Ownership: Copper Hull	30 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
1	5	18,892	12,668	-6,225
1	7.5	18,892	11,663	-7,229
1	10	18,892	11,176	-7,717
1	15	18,892	10,716	-8,177
2	5	13,082	12,668	-414
2	7.5	13,082	11,663	-1,419
2	10	13,082	11,176	-1,906
2	15	13,082	10,716	-2,366
2.5	5	11,922	12,668	745
2.5	7.5	11,922	11,663	-259
2.5	10	11,922	11,176	-747
2.5	15	11,922	10,716	-1,207
3	5	11,151	12,668	1,517
3	7.5	11,151	11,663	512
3	10	11,151	11,176	25
3	15	11,151	10,716	-436
4	5	10,226	12,668	2,442
4	7.5	10,226	11,663	1,438
4	10	10,226	11,176	950
4	15	10,226	10,716	490

Figure D2-D: Comparison of Different Hull Cleaning Regimes

Cu Cleaning Freq (x's/yr)	Epoxy Cleaning Freq (x's/yr)	30 Year Cost of Ownership: Copper Hull	30 Year Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
10	22	10,332	11,663	1,331
10	26	10,332	13,253	2,921
14	22	11,922	11,663	-259
14	26	11,922	13,253	1,331

Figure D-3: Comparison of Different Boat Lifetimes and Stripping Frequencies (New Boats)

Default Assumptions

Discount Rate = 5%

Stripping Cost = $120/ft.

Cu cost: $30/ft; Cu duration: 2.5 years, Cu cleaning: 14 times/year

Epoxy duration: 7.5 years; Epoxy cleaning: 22 times/year

Boat Life (yrs)	Stripping Freq. (yrs)	Cost of Epoxy ($/ft)	Cost of Ownership: Copper Hull	Cost of Ownership: Epoxy Hull	Difference (Epoxy - Copper)
30	15	30	11,922	10,934	-989
30	15	40	11,922	11,663	-259
30	15	50	11,922	12,393	470
30	17.5	30	11,682	10,934	-748
30	17.5	40	11,682	11,663	-19
30	17.5	50	11,682	12,393	711
30	20	30	11,494	10,934	-560
30	20	40	11,494	11,663	170
30	20	50	11,494	12,393	899
35	15	30	12,312	11,105	-1,207
35	15	40	12,312	11,856	-456
35	15	50	12,312	12,607	295
35	17.5	30	11,814	11,105	-709
35	17.5	40	11,814	11,856	42
35	17.5	50	11,814	12,607	792
35	20	30	11,626	11,105	-521
35	20	40	11,626	11,856	230
35	20	50	11,626	12,607	981
40	15	30	12,416	11,189	-1,227
40	15	40	12,416	11,940	-476
40	15	50	12,416	12,691	275
40	17.5	30	11,918	11,189	-729
40	17.5	40	11,918	11,940	22
40	17.5	50	11,918	12,691	773
40	20	30	11,730	11,189	-541
40	20	40	11,730	11,940	210
40	20	50	11,730	12,691	961

APPENDIX E : POLICY COST CALCULATIONS

Figure E-1: Summary Tables

Costs of Alternative Policies: 100% Reduction

Policy	Cost to Old	Cost to New	Total Cost
Immediate	33,780,292	-30,241	33,750,051
Random	25,764,630	-453,621	25,311,009
Subsidy	22,641,358	-453,621	22,187,737
Copper	20,084,632	-453,621	19,631,011
Least Cost	2,419,972	-907,242	1,512,730

Costs of Alternative Policies: 66% Reduction

Policy	Cost to Old	Cost to New	Total Cost
Immediate	N/A	N/A	N/A
Random	18,665,043	-272,173	18,392,870
Subsidy	13,856,932	-272,173	13,584,759
Copper	12,292,168	-277,624	12,014,543
Least Cost	1,613,315	-604,828	1,008,487

Figure E-2: Costs of Ownership Calculations - Boat Painted with Cu at Time 0

Cost of Copper: **60,412,062**

Assumptions

# Boats	7,000
Boat Size	40
Boat Life	30
Disc. Rate	5%

Painting Costs

Paint	Cost (per ft)	Freq.
High Cu	30	2.5
Epoxy	40	7.5
Stripping	120	15

Cleaning Costs

Paint	Cost (per ft)	Freq. (per year)
High Cu	1	14
Epoxy	1	22

Boat Age (Periods)	# Boats	# Cleanings	Cleaning Cost	# Paintings	Paint Cost	# Strippings	Stripping Cost	Total Cost	Remaining Ownership Cost: Copper Hull (NPV)	Total Remaining Cost: All Copper Hulls
0	117	7	280	1	1,200	0	0	1,480	11,922	1,390,952
1	117	7	280	0	0	0	0	280	10,965	1,279,200
2	117	7	280	0	0	0	0	280	11,219	1,308,860
3	117	7	280	0	0	0	0	280	11,486	1,340,003
4	117	7	280	0	0	0	0	280	11,766	1,372,703
5	117	7	280	1	1,200	0	0	1,480	12,060	1,407,038
6	117	7	280	0	0	0	0	280	11,109	1,296,090
7	117	7	280	0	0	0	0	280	11,371	1,326,595
8	117	7	280	0	0	0	0	280	11,645	1,358,625
9	117	7	280	0	0	0	0	280	11,934	1,392,256
10	117	7	280	1	1,200	0	0	1,480	12,236	1,427,569
11	117	7	280	0	0	0	0	280	11,294	1,317,647
12	117	7	280	0	0	0	0	280	11,565	1,349,229
13	117	7	280	0	0	0	0	280	11,849	1,382,391
14	117	7	280	0	0	0	0	280	12,148	1,417,210
15	117	7	280	1	1,200	0	0	1,480	12,461	1,453,771
16	117	7	280	0	0	0	0	280	11,530	1,345,159
17	117	7	280	0	0	0	0	280	11,812	1,378,117
18	117	7	280	0	0	0	0	280	12,109	1,412,723
19	117	7	280	0	0	0	0	280	12,421	1,449,059
20	117	7	280	1	1,200	0	0	1,480	12,748	1,487,212
21	117	7	280	0	0	0	0	280	11,831	1,380,273
22	117	7	280	0	0	0	0	280	12,128	1,414,987
23	117	7	280	0	0	0	0	280	12,441	1,451,436
24	117	7	280	0	0	0	0	280	12,769	1,489,708
25	117	7	280	1	1,200	0	0	1,480	13,113	1,529,893
26	117	7	280	0	0	0	0	280	12,215	1,425,088
27	117	7	280	0	0	0	0	280	12,532	1,462,042
28	117	7	280	0	0	0	0	280	12,864	1,500,844
29	117	7	280	0	0	0	0	280	13,214	1,541,587
30	117	7	280	1	1,200	1	4,800	6,280	13,580	1,584,366
31	117	7	280	0	0	0	0	280	7,665	894,284
32	117	7	280	0	0	0	0	280	7,755	904,698
33	117	7	280	0	0	0	0	280	7,848	915,633
34	117	7	280	0	0	0	0	280	7,947	927,115
35	117	7	280	1	1,200	0	0	1,480	8,050	939,171
36	117	7	280	0	0	0	0	280	6,899	804,829
37	117	7	280	0	0	0	0	280	6,949	810,771
38	117	7	280	0	0	0	0	280	7,003	817,009
39	117	7	280	0	0	0	0	280	7,059	823,560
40	117	7	280	1	1,200	0	0	1,480	7,118	830,438
41	117	7	280	0	0	0	0	280	5,920	690,660
42	117	7	280	0	0	0	0	280	5,922	690,893
43	117	7	280	0	0	0	0	280	5,924	691,137
44	117	7	280	0	0	0	0	280	5,926	691,394
45	117	7	280	1	1,200	0	0	1,480	5,929	691,664
46	117	7	280	0	0	0	0	280	4,671	544,947
47	117	7	280	0	0	0	0	280	4,611	537,894
48	117	7	280	0	0	0	0	280	4,547	530,489
49	117	7	280	0	0	0	0	280	4,480	522,713
50	117	7	280	1	1,200	0	0	1,480	4,410	514,549
51	117	7	280	0	0	0	0	280	3,077	358,977
52	117	7	280	0	0	0	0	280	2,937	342,625
53	117	7	280	0	0	0	0	280	2,790	325,457
54	117	7	280	0	0	0	0	280	2,635	307,430
55	117	7	280	1	1,200	0	0	1,480	2,473	288,501
56	117	7	280	0	0	0	0	280	1,043	121,626
57	117	7	280	0	0	0	0	280	801	93,407
58	117	7	280	0	0	0	0	280	547	63,778
59	117	7	280	0	0	0	0	280	547	63,778

Figure E-3: Costs Calculations - All Boats Converted to Epoxy at Time 0

Cost of Copper: 60,412,062
Cost of Epoxy: 94,162,113
Cost of Policy: **33,750,051**

Cost to New Boats: -30,241
Cost to Old Boats: 33,780,292

Boat Age (Periods)	# Boats	# Cleanings	Cleaning Cost	# Paintings	Paint Cost	# Strippings	Stripping Cost	Total Cost	Discount Factor	Disc. Total Cost	Remaining Cost of Own. Epoxy Hull	Total Remaining Cost: All Epoxy Hulls	Difference (Epoxy - Cu)
0	117	11	440	1	1,600	0	0	2,040	1.00	2,040	11,663	1,360,711	-259
1	117	11	440	0	0	0	0	440	0.95	419	16,439	1,917,825	5,474
2	117	11	440	0	0	0	0	440	0.91	399	16,413	1,914,796	5,194
3	117	11	440	0	0	0	0	440	0.86	380	16,385	1,911,614	4,900
4	117	11	440	0	0	0	0	440	0.82	362	16,357	1,908,274	4,591
5	117	11	440	0	0	0	0	440	0.78	345	16,327	1,904,766	4,266
6	117	11	440	0	0	0	0	440	0.75	328	16,295	1,901,084	5,186
7	117	11	440	0	0	0	0	440	0.71	313	16,262	1,897,217	4,891
8	117	11	440	0	0	0	0	440	0.68	298	16,227	1,893,156	4,582
9	117	11	440	0	0	0	0	440	0.64	284	16,191	1,888,893	4,257
10	117	11	440	0	0	0	0	440	0.61	270	16,152	1,884,417	3,916
11	117	11	440	0	0	0	0	440	0.58	257	16,112	1,879,716	4,818
12	117	11	440	0	0	0	0	440	0.56	245	16,070	1,874,781	4,505
13	117	11	440	0	0	0	0	440	0.53	233	16,025	1,869,599	4,176
14	117	11	440	0	0	0	0	440	0.51	222	15,978	1,864,158	3,831
15	117	11	440	1	1,600	0	0	2,040	0.48	981	15,751	1,837,669	3,291
16	117	11	440	0	0	0	0	440	0.46	202	15,700	1,831,670	4,170
17	117	11	440	0	0	0	0	440	0.44	192	15,646	1,825,372	3,834
18	117	11	440	0	0	0	0	440	0.42	183	15,589	1,818,758	3,480
19	117	11	440	0	0	0	0	440	0.40	174	15,530	1,811,813	3,109
20	117	11	440	0	0	0	0	440	0.38	166	15,467	1,804,522	2,720
21	117	11	440	0	0	0	0	440	0.36	158	15,402	1,796,865	3,571
22	117	11	440	0	0	0	0	440	0.34	150	15,333	1,788,826	3,204
23	117	11	440	0	0	0	0	440	0.33	143	15,260	1,780,385	2,820
24	117	11	440	0	0	0	0	440	0.31	136	15,184	1,771,522	2,416
25	117	11	440	0	0	0	0	440	0.30	130	15,105	1,762,216	1,991
26	117	11	440	0	0	0	0	440	0.28	124	15,021	1,752,445	2,806
27	117	11	440	0	0	0	0	440	0.27	118	14,933	1,742,184	2,401
28	117	11	440	0	0	0	0	440	0.26	112	14,841	1,731,411	1,976
29	117	11	440	0	0	0	0	440	0.24	107	14,744	1,720,099	1,530
30	117	11	440	1	1,600	0	0	2,040	0.23	472	14,272	1,665,032	691
31	117	11	440	0	0	0	0	440	0.22	97	14,165	1,652,560	6,500
32	117	11	440	0	0	0	0	440	0.21	92	14,053	1,639,466	6,298
33	117	11	440	0	0	0	0	440	0.20	88	13,935	1,625,716	6,086
34	117	11	440	0	0	0	0	440	0.19	84	13,811	1,611,279	5,864
35	117	11	440	0	0	0	0	440	0.18	80	13,681	1,596,120	5,631
36	117	11	440	0	0	0	0	440	0.17	76	13,545	1,580,203	6,646
37	117	11	440	0	0	0	0	440	0.16	72	13,401	1,563,491	6,452
38	117	11	440	0	0	0	0	440	0.16	69	13,251	1,545,942	6,248
39	117	11	440	0	0	0	0	440	0.15	66	13,093	1,527,517	6,034
40	117	11	440	0	0	0	0	440	0.14	63	12,927	1,508,170	5,809
41	117	11	440	0	0	0	0	440	0.14	60	12,753	1,487,855	6,833
42	117	11	440	0	0	0	0	440	0.13	57	12,570	1,466,525	6,648
43	117	11	440	0	0	0	0	440	0.12	54	12,378	1,444,129	6,454
44	117	11	440	0	0	0	0	440	0.12	51	12,177	1,420,612	6,250
45	117	11	440	1	1,600	0	0	2,040	0.11	227	11,195	1,306,130	5,267
46	117	11	440	0	0	0	0	440	0.11	47	10,973	1,280,203	6,302
47	117	11	440	0	0	0	0	440	0.10	44	10,740	1,252,980	6,129
48	117	11	440	0	0	0	0	440	0.10	42	10,495	1,224,396	5,948
49	117	11	440	0	0	0	0	440	0.09	40	10,238	1,194,382	5,757
50	117	11	440	0	0	0	0	440	0.09	38	9,967	1,162,868	5,557
51	117	11	440	0	0	0	0	440	0.08	37	9,684	1,129,778	6,607
52	117	11	440	0	0	0	0	440	0.08	35	9,386	1,095,034	6,449
53	117	11	440	0	0	0	0	440	0.08	33	9,073	1,058,552	6,284
54	117	11	440	0	0	0	0	440	0.07	32	8,745	1,020,246	6,110
55	117	11	440	0	0	0	0	440	0.07	30	8,400	980,025	5,927
56	117	11	440	0	0	0	0	440	0.07	29	8,038	937,793	6,996
57	117	11	440	0	0	0	0	440	0.06	27	7,658	893,450	6,858
58	117	11	440	0	0	0	0	440	0.06	26	7,259	846,889	6,712
59	117	11	440	0	0	0	0	440	0.06	25	6,840	798,000	6,293

Figure E-4: Costs Calculations – Randomly Selected Boats Converted in Quickest Time

	100%		66%
Cost to New Boats:	-453,621	Cost to New Boats:	-272,173
Cost to Old Boats:	25,764,630	Cost to Old Boats:	18,665,043
Total Cost:	**25,311,009**	Total Cost:	**18,392,870**

Period	Demand, Cu	Demand, NT	Demand	# Painted Cu	# Painted NT	# Converted	Converted: Selected	New	NT Boats	Cu Boats	Total Cost - Old	Total Cost - New
1	1,400	0	1,400	1,027	373	373	257	117	373	6,627	1,259,604	-30,241
2	1,400	0	1,400	1,027	373	373	257	117	747	6,253	1,259,604	-30,241
3	1,400	0	1,400	1,027	373	373	257	117	1,120	5,880	1,259,604	-30,241
4	1,400	0	1,400	1,027	373	373	257	117	1,493	5,507	1,259,604	-30,241
5	1,400	0	1,400	1,027	373	373	257	117	1,867	5,133	1,259,604	-30,241
6	1,027	0	1,027	280	747	747	630	117	2,613	4,387	3,091,756	-30,241
7	1,027	0	1,027	280	747	747	630	117	3,360	3,640	3,091,756	-30,241
8	1,027	0	1,027	280	747	747	630	117	4,107	2,893	3,091,756	-30,241
9	1,027	0	1,027	280	747	747	630	117	4,853	2,147	3,091,756	-30,241
10	1,027	0	1,027	280	747	747	630	117	5,600	1,400	3,091,756	-30,241
11	280	0	280	0	280	280	163	117	5,880	1,120	801,566	-30,241
12	280	0	280	0	280	280	163	117	6,160	840	801,566	-30,241
13	280	0	280	0	280	280	163	117	6,440	560	801,566	-30,241
14	280	0	280	0	280	280	163	117	6,720	280	801,566	-30,241
15	280	0	280	0	280	280	163	117	7,000	0	801,566	-30,241
16	0	373	373	0	373	0	0	0	7,000	0	0	0
17	0	373	373	0	373	0	0	0	7,000	0	0	0
18	0	373	373	0	373	0	0	0	7,000	0	0	0
19	0	373	373	0	373	0	0	0	7,000	0	0	0
20	0	373	373	0	373	0	0	0	7,000	0	0	0
21	0	747	747	0	747	0	0	0	7,000	0	0	0
22	0	747	747	0	747	0	0	0	7,000	0	0	0
23	0	747	747	0	747	0	0	0	7,000	0	0	0
24	0	747	747	0	747	0	0	0	7,000	0	0	0
25	0	747	747	0	747	0	0	0	7,000	0	0	0
26	0	280	280	0	280	0	0	0	7,000	0	0	0
27	0	280	280	0	280	0	0	0	7,000	0	0	0
28	0	280	280	0	280	0	0	0	7,000	0	0	0
29	0	280	280	0	280	0	0	0	7,000	0	0	0
30	0	280	280	0	280	0	0	0	7,000	0	0	0
31	0	373	373	0	373	0	0	0	7,000	0	0	0
32	0	373	373	0	373	0	0	0	7,000	0	0	0
33	0	373	373	0	373	0	0	0	7,000	0	0	0
34	0	373	373	0	373	0	0	0	7,000	0	0	0
35	0	373	373	0	373	0	0	0	7,000	0	0	0
36	0	747	747	0	747	0	0	0	7,000	0	0	0
37	0	747	747	0	747	0	0	0	7,000	0	0	0
38	0	747	747	0	747	0	0	0	7,000	0	0	0
39	0	747	747	0	747	0	0	0	7,000	0	0	0
40	0	747	747	0	747	0	0	0	7,000	0	0	0
41	0	280	280	0	280	0	0	0	7,000	0	0	0
42	0	280	280	0	280	0	0	0	7,000	0	0	0
43	0	280	280	0	280	0	0	0	7,000	0	0	0
44	0	280	280	0	280	0	0	0	7,000	0	0	0
45	0	280	280	0	280	0	0	0	7,000	0	0	0
46	0	373	373	0	373	0	0	0	7,000	0	0	0
47	0	373	373	0	373	0	0	0	7,000	0	0	0
48	0	373	373	0	373	0	0	0	7,000	0	0	0
49	0	373	373	0	373	0	0	0	7,000	0	0	0
50	0	373	373	0	373	0	0	0	7,000	0	0	0
51	0	747	747	0	747	0	0	0	7,000	0	0	0
52	0	747	747	0	747	0	0	0	7,000	0	0	0
53	0	747	747	0	747	0	0	0	7,000	0	0	0
54	0	747	747	0	747	0	0	0	7,000	0	0	0
55	0	747	747	0	747	0	0	0	7,000	0	0	0
56	0	280	280	0	280	0	0	0	7,000	0	0	0
57	0	280	280	0	280	0	0	0	7,000	0	0	0
58	0	280	280	0	280	0	0	0	7,000	0	0	0
59	0	280	280	0	280	0	0	0	7,000	0	0	0
60	0	280	280	0	280	0	0	0	7,000	0	0	0

Figure E-5: Costs Calculations – Subsidy to Convert Boats in Quickest Time

	100%		66%
Cost to New Boats:	-453,621	Cost to New Boats:	-272,173
Cost to Old Boats:	20,112,640	Cost to Old Boats:	14,570,490
Total Cost:	**19,659,019**	Total Cost:	**14,298,318**

Period	Demand, Cu	Demand, NT	Demand	# Painted Cu	# Painted NT	# Converted	# New	NT Boats	Cu Boats	# Subsidized	Total Cost - Old	Total Cost - New
1	1,400	0	1,400	1,027	373	373	117	373	6,627	257	983,285	-30,241
2	1,400	0	1,400	1,027	373	373	117	747	6,253	257	983,285	-30,241
3	1,400	0	1,400	1,027	373	373	117	1,120	5,880	257	983,285	-30,241
4	1,400	0	1,400	1,027	373	373	117	1,493	5,507	257	983,285	-30,241
5	1,400	0	1,400	1,027	373	373	117	1,867	5,133	257	983,285	-30,241
6	1,027	0	1,027	280	747	747	117	2,613	4,387	630	2,413,517	-30,241
7	1,027	0	1,027	280	747	747	117	3,360	3,640	630	2,413,517	-30,241
8	1,027	0	1,027	280	747	747	117	4,107	2,893	630	2,413,517	-30,241
9	1,027	0	1,027	280	747	747	117	4,853	2,147	630	2,413,517	-30,241
10	1,027	0	1,027	280	747	747	117	5,600	1,400	630	2,413,517	-30,241
11	280	0	280	0	280	280	117	5,880	1,120	163	625,727	-30,241
12	280	0	280	0	280	280	117	6,160	840	163	625,727	-30,241
13	280	0	280	0	280	280	117	6,440	560	163	625,727	-30,241
14	280	0	280	0	280	280	117	6,720	280	163	625,727	-30,241
15	280	0	280	0	280	280	117	7,000	0	163	625,727	-30,241
16	0	373	373	0	373	0	0	7,000	0	0	0	0
17	0	373	373	0	373	0	0	7,000	0	0	0	0
18	0	373	373	0	373	0	0	7,000	0	0	0	0
19	0	373	373	0	373	0	0	7,000	0	0	0	0
20	0	373	373	0	373	0	0	7,000	0	0	0	0
21	0	747	747	0	747	0	0	7,000	0	0	0	0
22	0	747	747	0	747	0	0	7,000	0	0	0	0
23	0	747	747	0	747	0	0	7,000	0	0	0	0
24	0	747	747	0	747	0	0	7,000	0	0	0	0
25	0	747	747	0	747	0	0	7,000	0	0	0	0
26	0	280	280	0	280	0	0	7,000	0	0	0	0
27	0	280	280	0	280	0	0	7,000	0	0	0	0
28	0	280	280	0	280	0	0	7,000	0	0	0	0
29	0	280	280	0	280	0	0	7,000	0	0	0	0
30	0	280	280	0	280	0	0	7,000	0	0	0	0
31	0	373	373	0	373	0	0	7,000	0	0	0	0
32	0	373	373	0	373	0	0	7,000	0	0	0	0
33	0	373	373	0	373	0	0	7,000	0	0	0	0
34	0	373	373	0	373	0	0	7,000	0	0	0	0
35	0	373	373	0	373	0	0	7,000	0	0	0	0
36	0	747	747	0	747	0	0	7,000	0	0	0	0
37	0	747	747	0	747	0	0	7,000	0	0	0	0
38	0	747	747	0	747	0	0	7,000	0	0	0	0
39	0	747	747	0	747	0	0	7,000	0	0	0	0
40	0	747	747	0	747	0	0	7,000	0	0	0	0
41	0	280	280	0	280	0	0	7,000	0	0	0	0
42	0	280	280	0	280	0	0	7,000	0	0	0	0
43	0	280	280	0	280	0	0	7,000	0	0	0	0
44	0	280	280	0	280	0	0	7,000	0	0	0	0
45	0	280	280	0	280	0	0	7,000	0	0	0	0
46	0	373	373	0	373	0	0	7,000	0	0	0	0
47	0	373	373	0	373	0	0	7,000	0	0	0	0
48	0	373	373	0	373	0	0	7,000	0	0	0	0
49	0	373	373	0	373	0	0	7,000	0	0	0	0
50	0	373	373	0	373	0	0	7,000	0	0	0	0
51	0	747	747	0	747	0	0	7,000	0	0	0	0
52	0	747	747	0	747	0	0	7,000	0	0	0	0
53	0	747	747	0	747	0	0	7,000	0	0	0	0
54	0	747	747	0	747	0	0	7,000	0	0	0	0
55	0	747	747	0	747	0	0	7,000	0	0	0	0
56	0	280	280	0	280	0	0	7,000	0	0	0	0
57	0	280	280	0	280	0	0	7,000	0	0	0	0
58	0	280	280	0	280	0	0	7,000	0	0	0	0
59	0	280	280	0	280	0	0	7,000	0	0	0	0
60	0	280	280	0	280	0	0	7,000	0	0	0	0

Figures E-6: Costs Calculations – Increase Price of Cu to Convert Boats in Quickest Time

E-6A : Costs of Ownership - Boat Painted with Cu at Time 0 with Tax

Boat Age (Periods)	# Boats	# Cleanings	Cleaning Cost	# Paintings	Paint Cost	# Strippings	Stripping Cost	Total Cost	Ownership Cost:	Cost: All Copper Hulls
0	1	7	280	1	2,181	0	0	2,461	16,212	16,212
1	1	7	280	0	0	0	0	280	14,439	14,439
2	1	7	280	0	0	0	0	280	14,867	14,867
3	1	7	280	0	0	0	0	280	15,316	15,316
4	1	7	280	0	0	0	0	280	15,788	15,788
5	1	7	280	1	2,181	0	0	2,461	16,283	16,283
6	1	7	280	0	0	0	0	280	14,513	14,513
7	1	7	280	0	0	0	0	280	14,945	14,945
8	1	7	280	0	0	0	0	280	15,398	15,398
9	1	7	280	0	0	0	0	280	15,874	15,874
10	1	7	280	1	2,181	0	0	2,461	16,374	16,374
11	1	7	280	0	0	0	0	280	14,608	14,608
12	1	7	280	0	0	0	0	280	15,045	15,045
13	1	7	280	0	0	0	0	280	15,503	15,503
14	1	7	280	0	0	0	0	280	15,984	15,984
15	0	7	280	1	2,181	0	0	2,461	16,489	0
16	0	7	280	0	0	0	0	280	14,729	0
17	0	7	280	0	0	0	0	280	15,172	0
18	0	7	280	0	0	0	0	280	15,636	0
19	0	7	280	0	0	0	0	280	16,124	0
20	0	7	280	1	2,181	0	0	2,461	16,636	0
21	0	7	280	0	0	0	0	280	14,884	0
22	0	7	280	0	0	0	0	280	15,334	0
23	0	7	280	0	0	0	0	280	15,807	0
24	0	7	280	0	0	0	0	280	16,303	0
25	0	7	280	1	2,181	0	0	2,461	16,824	0
26	0	7	280	0	0	0	0	280	15,081	0
27	0	7	280	0	0	0	0	280	15,541	0
28	0	7	280	0	0	0	0	280	16,024	0
29	0	7	280	0	0	0	0	280	16,532	0
30	0	7	280	1	2,181	1	4,800	7,261	17,064	0
31	0	7	280	0	0	0	0	280	10,293	0
32	0	7	280	0	0	0	0	280	10,514	0
33	0	7	280	0	0	0	0	280	10,745	0
34	0	7	280	0	0	0	0	280	10,989	0
35	0	7	280	1	2,181	0	0	2,461	11,244	0
36	0	7	280	0	0	0	0	280	9,222	0
37	0	7	280	0	0	0	0	280	9,389	0
38	0	7	280	0	0	0	0	280	9,565	0
39	0	7	280	0	0	0	0	280	9,749	0
40	0	7	280	1	2,181	0	0	2,461	9,942	0
41	0	7	280	0	0	0	0	280	7,855	0
42	0	7	280	0	0	0	0	280	7,954	0
43	0	7	280	0	0	0	0	280	8,058	0
44	0	7	280	0	0	0	0	280	8,167	0
45	0	7	280	1	2,181	0	0	2,461	8,281	0
46	0	7	280	0	0	0	0	280	6,111	0
47	0	7	280	0	0	0	0	280	6,122	0
48	0	7	280	0	0	0	0	280	6,134	0
49	0	7	280	0	0	0	0	280	6,147	0
50	0	7	280	1	2,181	0	0	2,461	6,160	0
51	0	7	280	0	0	0	0	280	3,884	0
52	0	7	280	0	0	0	0	280	3,784	0
53	0	7	280	0	0	0	0	280	3,680	0
54	0	7	280	0	0	0	0	280	3,570	0
55	0	7	280	1	2,181	0	0	2,461	3,454	0
56	0	7	280	0	0	0	0	280	1,043	0
57	0	7	280	0	0	0	0	280	801	0
58	0	7	280	0	0	0	0	280	547	0
59	0	7	280	0	0	0	0	280	547	0

E-6B : Costs of Ownership - Boat Painted with Epoxy at Time 0 with Tax

Boat Age (Periods)	# Boats	# Cleanings	Cleaning Cost	# Paintings	Paint Cost	# Strippings	Stripping Cost	Total Cost	Discount Factor	Disc. Total Cost	Cost of Own. Epoxy Hull	Cost: All Epoxy Hulls	Difference (Epoxy - Cu)
0	117	11	440	1	1,600	0	0	2,040	1.00	2,040	11,663	1,360,711	-4,549
1	117	11	440	0	0	0	0	440	0.95	419	16,439	1,917,825	2,000
2	117	11	440	0	0	0	0	440	0.91	399	16,413	1,914,796	1,546
3	117	11	440	0	0	0	0	440	0.86	380	16,385	1,911,614	1,069
4	117	11	440	0	0	0	0	440	0.82	362	16,357	1,908,274	569
5	117	11	440	0	0	0	0	440	0.78	345	16,327	1,904,766	43
6	117	11	440	0	0	0	0	440	0.75	328	16,295	1,901,084	1,782
7	117	11	440	0	0	0	0	440	0.71	313	16,262	1,897,217	1,317
8	117	11	440	0	0	0	0	440	0.68	298	16,227	1,893,156	829
9	117	11	440	0	0	0	0	440	0.64	284	16,191	1,888,893	317
10	117	11	440	0	0	0	0	440	0.61	270	16,152	1,884,417	-222
11	117	11	440	0	0	0	0	440	0.58	257	16,112	1,879,716	1,504
12	117	11	440	0	0	0	0	440	0.56	245	16,070	1,874,781	1,025
13	117	11	440	0	0	0	0	440	0.53	233	16,025	1,869,599	522
14	117	11	440	0	0	0	0	440	0.51	222	15,978	1,864,158	-5
15	117	11	440	1	1,600	0	0	2,040	0.48	981	15,751	1,837,669	-738
16	117	11	440	0	0	0	0	440	0.46	202	15,700	1,831,670	971
17	117	11	440	0	0	0	0	440	0.44	192	15,646	1,825,372	474
18	117	11	440	0	0	0	0	440	0.42	183	15,589	1,818,758	-47
19	117	11	440	0	0	0	0	440	0.40	174	15,530	1,811,813	-594
20	117	11	440	0	0	0	0	440	0.38	166	15,467	1,804,522	-1,169
21	117	11	440	0	0	0	0	440	0.36	158	15,402	1,796,865	518
22	117	11	440	0	0	0	0	440	0.34	150	15,333	1,788,826	-1
23	117	11	440	0	0	0	0	440	0.33	143	15,260	1,780,385	-546
24	117	11	440	0	0	0	0	440	0.31	136	15,184	1,771,522	-1,119
25	117	11	440	0	0	0	0	440	0.30	130	15,105	1,762,216	-1,720
26	117	11	440	0	0	0	0	440	0.28	124	15,021	1,752,445	-60
27	117	11	440	0	0	0	0	440	0.27	118	14,933	1,742,184	-608
28	117	11	440	0	0	0	0	440	0.26	112	14,841	1,731,411	-1,184
29	117	11	440	0	0	0	0	440	0.24	107	14,744	1,720,099	-1,788
30	117	11	440	1	1,600	0	0	2,040	0.23	472	14,272	1,665,032	-2,792
31	117	11	440	0	0	0	0	440	0.22	97	14,165	1,652,560	3,872
32	117	11	440	0	0	0	0	440	0.21	92	14,053	1,639,466	3,539
33	117	11	440	0	0	0	0	440	0.20	88	13,935	1,625,716	3,189
34	117	11	440	0	0	0	0	440	0.19	84	13,811	1,611,279	2,822
35	117	11	440	0	0	0	0	440	0.18	80	13,681	1,596,120	2,437
36	117	11	440	0	0	0	0	440	0.17	76	13,545	1,580,203	4,322
37	117	11	440	0	0	0	0	440	0.16	72	13,401	1,563,491	4,012
38	117	11	440	0	0	0	0	440	0.16	69	13,251	1,545,942	3,686
39	117	11	440	0	0	0	0	440	0.15	66	13,093	1,527,517	3,344
40	117	11	440	0	0	0	0	440	0.14	63	12,927	1,508,170	2,985
41	117	11	440	0	0	0	0	440	0.14	60	12,753	1,487,855	4,898
42	117	11	440	0	0	0	0	440	0.13	57	12,570	1,466,525	4,616
43	117	11	440	0	0	0	0	440	0.12	54	12,378	1,444,129	4,321
44	117	11	440	0	0	0	0	440	0.12	51	12,177	1,420,612	4,010
45	117	11	440	1	1,600	0	0	2,040	0.11	227	11,195	1,306,130	2,914
46	117	11	440	0	0	0	0	440	0.11	47	10,973	1,280,203	4,862
47	117	11	440	0	0	0	0	440	0.10	44	10,740	1,252,980	4,618
48	117	11	440	0	0	0	0	440	0.10	42	10,495	1,224,396	4,360
49	117	11	440	0	0	0	0	440	0.09	40	10,238	1,194,382	4,090
50	117	11	440	0	0	0	0	440	0.09	38	9,967	1,162,868	3,807
51	117	11	440	0	0	0	0	440	0.08	37	9,684	1,129,778	5,800
52	117	11	440	0	0	0	0	440	0.08	35	9,386	1,095,034	5,602
53	117	11	440	0	0	0	0	440	0.08	33	9,073	1,058,552	5,394
54	117	11	440	0	0	0	0	440	0.07	32	8,745	1,020,246	5,175
55	117	11	440	0	0	0	0	440	0.07	30	8,400	980,025	4,946
56	117	11	440	0	0	0	0	440	0.07	29	8,038	937,793	6,996
57	117	11	440	0	0	0	0	440	0.06	27	7,658	893,450	6,858
58	117	11	440	0	0	0	0	440	0.06	26	7,259	846,889	6,712
59	117	11	440	0	0	0	0	440	0.06	25	6,840	798,000	6,293

Figure E-6C: Costs of Policy to Increase Price of Cu to Convert Boats in Quickest Time

	100%		**66%**
Cost to New Boats:	-453,621	Cost to New Boats:	-272,173
Cost to Old Boats:	16,867,571	Cost to Old Boats:	14,597,154
Total Cost:	**16,413,950**	Total Cost:	**14,324,982**

Period	Demand, Cu	Demand, NT	Demand	# Painted Cu	# Painted NT	# Converted	# New	NT Boats	Cu Boats	# Needed to Convert Volunarily	Total Cost - Old	Total Cost - New
1	1,400	0	1,400	1,027	373	373	117	373	6,627	257	405,327	-30,241
2	1,400	0	1,400	1,027	373	373	117	747	6,253	257	425,593	-30,241
3	1,400	0	1,400	1,027	373	373	117	1,120	5,880	257	446,873	-30,241
4	1,400	0	1,400	1,027	373	373	117	1,493	5,507	257	469,217	-30,241
5	1,400	0	1,400	1,027	373	373	117	1,867	5,133	257	492,677	-30,241
6	1,027	0	1,027	280	747	747	117	2,613	4,387	630	397,114	-30,241
7	1,027	0	1,027	280	747	747	117	3,360	3,640	630	416,970	-30,241
8	1,027	0	1,027	280	747	747	117	4,107	2,893	630	437,819	-30,241
9	1,027	0	1,027	280	747	747	117	4,853	2,147	630	459,710	-30,241
10	1,027	0	1,027	280	747	747	117	5,600	1,400	630	456,848	-30,241
11	280	0	280	0	280	280	117	5,880	1,120	163	386,633	-30,241
12	280	0	280	0	280	280	117	6,160	840	163	405,964	-30,241
13	280	0	280	0	280	280	117	6,440	560	163	426,263	-30,241
14	280	0	280	0	280	280	117	6,720	280	163	446,948	-30,241
15	280	0	280	0	280	280	117	7,000	0	163	383,898	-30,241
16	0	373	373	0	373	0	0	7,000	0	0	373,255	0
17	0	373	373	0	373	0	0	7,000	0	0	391,918	0
18	0	373	373	0	373	0	0	7,000	0	0	406,035	0
19	0	373	373	0	373	0	0	7,000	0	0	362,754	0
20	0	373	373	0	373	0	0	7,000	0	0	317,309	0
21	0	747	747	0	747	0	0	7,000	0	0	356,182	0
22	0	747	747	0	747	0	0	7,000	0	0	373,840	0
23	0	747	747	0	747	0	0	7,000	0	0	328,949	0
24	0	747	747	0	747	0	0	7,000	0	0	281,814	0
25	0	747	747	0	747	0	0	7,000	0	0	232,323	0
26	0	280	280	0	280	0	0	7,000	0	0	327,357	0
27	0	280	280	0	280	0	0	7,000	0	0	280,142	0
28	0	280	280	0	280	0	0	7,000	0	0	230,567	0
29	0	280	280	0	280	0	0	7,000	0	0	178,513	0
30	0	280	280	0	280	0	0	7,000	0	0	80,666	0
31	0	373	373	0	373	0	0	7,000	0	0	306,580	0
32	0	373	373	0	373	0	0	7,000	0	0	321,909	0
33	0	373	373	0	373	0	0	7,000	0	0	338,005	0
34	0	373	373	0	373	0	0	7,000	0	0	354,905	0
35	0	373	373	0	373	0	0	7,000	0	0	372,650	0
36	0	747	747	0	747	0	0	7,000	0	0	271,086	0
37	0	747	747	0	747	0	0	7,000	0	0	284,640	0
38	0	747	747	0	747	0	0	7,000	0	0	298,872	0
39	0	747	747	0	747	0	0	7,000	0	0	313,816	0
40	0	747	747	0	747	0	0	7,000	0	0	329,507	0
41	0	280	280	0	280	0	0	7,000	0	0	225,785	0
42	0	280	280	0	280	0	0	7,000	0	0	237,074	0
43	0	280	280	0	280	0	0	7,000	0	0	248,928	0
44	0	280	280	0	280	0	0	7,000	0	0	261,374	0
45	0	280	280	0	280	0	0	7,000	0	0	274,443	0
46	0	373	373	0	373	0	0	7,000	0	0	167,968	0
47	0	373	373	0	373	0	0	7,000	0	0	176,366	0
48	0	373	373	0	373	0	0	7,000	0	0	185,185	0
49	0	373	373	0	373	0	0	7,000	0	0	194,444	0
50	0	373	373	0	373	0	0	7,000	0	0	204,166	0
51	0	747	747	0	747	0	0	7,000	0	0	94,177	0
52	0	747	747	0	747	0	0	7,000	0	0	98,886	0
53	0	747	747	0	747	0	0	7,000	0	0	103,831	0
54	0	747	747	0	747	0	0	7,000	0	0	109,022	0
55	0	747	747	0	747	0	0	7,000	0	0	114,473	0
56	0	280	280	0	280	0	0	7,000	0	0	0	0
57	0	280	280	0	280	0	0	7,000	0	0	0	0
58	0	280	280	0	280	0	0	7,000	0	0	0	0
59	0	280	280	0	280	0	0	7,000	0	0	0	0
60	0	280	280	0	280	0	0	7,000	0	0	0	0

Figure E-7: Costs Calculations – New and Stripped Boats Converted Over 15 Years

	100%		66%
Cost to New Boats:	-488,129	Cost to New Boats:	-395,718
Cost to Old Boats:	1,302,032	Cost to Old Boats:	1,055,537
Total Cost:	**813,903**	Total Cost:	**659,819**

Period	Boats Converted	# NT Boats	# Cu Boats	New Conv.	Stripped Conv.	Discount Factor	Cost to New	Cost to Stripped
0	233	233	6,767	117	117	1.00	-30,241	80,666
1	233	467	6,533	117	117	0.95	-28,801	76,825
2	233	700	6,300	117	117	0.91	-27,430	73,166
3	233	933	6,067	117	117	0.86	-26,124	69,682
4	233	1,167	5,833	117	117	0.82	-24,880	66,364
5	233	1,400	5,600	117	117	0.78	-23,695	63,204
6	233	1,633	5,367	117	117	0.75	-22,567	60,194
7	233	1,867	5,133	117	117	0.71	-21,492	57,328
8	233	2,100	4,900	117	117	0.68	-20,469	54,598
9	233	2,333	4,667	117	117	0.64	-19,494	51,998
10	233	2,567	4,433	117	117	0.61	-18,566	49,522
11	233	2,800	4,200	117	117	0.58	-17,682	47,164
12	233	3,033	3,967	117	117	0.56	-16,840	44,918
13	233	3,267	3,733	117	117	0.53	-16,038	42,779
14	233	3,500	3,500	117	117	0.51	-15,274	40,742
15	233	3,733	3,267	117	117	0.48	-14,547	38,802
16	233	3,967	3,033	117	117	0.46	-13,854	36,954
17	233	4,200	2,800	117	117	0.44	-13,194	35,194
18	233	4,433	2,567	117	117	0.42	-12,566	33,518
19	233	4,667	2,333	117	117	0.40	-11,968	31,922
20	233	4,900	2,100	117	117	0.38	-11,398	30,402
21	233	5,133	1,867	117	117	0.36	-10,855	28,954
22	233	5,367	1,633	117	117	0.34	-10,338	27,576
23	233	5,600	1,400	117	117	0.33	-9,846	26,262
24	233	5,833	1,167	117	117	0.31	-9,377	25,012
25	233	6,067	933	117	117	0.30	-8,930	23,821
26	233	6,300	700	117	117	0.28	-8,505	22,686
27	233	6,533	467	117	117	0.27	-8,100	21,606
28	233	6,767	233	117	117	0.26	-7,714	20,577
29	233	7,000	0	117	117	0.24	-7,347	19,597
30	0	7,000	0	0	0	0.23	0	0
31	0	7,000	0	0	0	0.22	0	0
32	0	7,000	0	0	0	0.21	0	0
33	0	7,000	0	0	0	0.20	0	0
34	0	7,000	0	0	0	0.19	0	0
35	0	7,000	0	0	0	0.18	0	0
36	0	7,000	0	0	0	0.17	0	0
37	0	7,000	0	0	0	0.16	0	0
38	0	7,000	0	0	0	0.16	0	0
39	0	7,000	0	0	0	0.15	0	0
40	0	7,000	0	0	0	0.14	0	0
41	0	7,000	0	0	0	0.14	0	0
42	0	7,000	0	0	0	0.13	0	0
43	0	7,000	0	0	0	0.12	0	0
44	0	7,000	0	0	0	0.12	0	0
45	0	7,000	0	0	0	0.11	0	0
46	0	7,000	0	0	0	0.11	0	0
47	0	7,000	0	0	0	0.10	0	0
48	0	7,000	0	0	0	0.10	0	0
49	0	7,000	0	0	0	0.09	0	0
50	0	7,000	0	0	0	0.09	0	0
51	0	7,000	0	0	0	0.08	0	0
52	0	7,000	0	0	0	0.08	0	0
53	0	7,000	0	0	0	0.08	0	0
54	0	7,000	0	0	0	0.07	0	0
55	0	7,000	0	0	0	0.07	0	0
56	0	7,000	0	0	0	0.07	0	0
57	0	7,000	0	0	0	0.06	0	0
58	0	7,000	0	0	0	0.06	0	0
59	0	7,000	0	0	0	0.06	0	0

APPENDIX F1 : SAMPLING PLAN

A stratified random sample of boats at marinas and mooring locations is drawn based upon the list in Appendix A1. The sampling plan is developed based upon the assumption that interviews at 9 different locations can be undertaken in person using 3 interviewers with some boaters being surveyed via mail.

Then objective is to complete 200 interviews, and from this overall objective the number of completed interviews that are needed at each marina/mooring location chosen is assigned. This sample allocation has been done so as to be a self-weighting stratified random sample.

More than 200 slips/occupied mooring locations will need to be sampled due to non-response by some boat owners. It assumed that a 50% response rate will be achieved.

Stratify Sample (7321 total slips/moored boats)

5 Areas Chosen for Stratification Based Upon Similarity of Area/Travel Considerations

9 Locations (multiple of 3 available interviewers)
Idealized location multiple is multiple of 11% of population

Chula Vista	12.6% of boats	1 marina to be sampled
Coronado	10.2% of boats	1 marina to be sampled
Downtown/Harbor Island	36.8% of boats	3 marinas to be sampled
Shelter Island	32.9% of boats	3 marinas to be sampled
Moorings	07.5% of boats	1 mooring to be sampled

Draw Stratified Random Sample of Marinas/Moorings using sample procedure in SPLUS.

```
S-PLUS : Copyright (c) 1988, 2001 Insightful Corp.
S : Copyright Lucent Technologies, Inc.
Professional Edition Version 6.0.3 Release 2 for Microsoft Windows : 2001
Working data will be in g:\Program Files\Insightful\splus6\users\temple

> #Chula Vista
> sample(c("CYM","CVM"),1,prob=c(365/926,561/926))
[1] "CVM"
> #Coronado
> sample(c("CCYC","CYC","FC","GBM","LCBR"),1,
+ prob=c(25/747,272/747,264/747,106/747,80/747))
[1] "CYC"
> #Downtown/Harbor Island
> sample(c("SDMM","CM","HIW","MC","SHIM","SRRM"),3,
+ prob=c(446/2969,450/2696,620/2696,525/2696,45/2696,610/2696))
[1] "HIW"  "CM"   "SRRM"
```

```
> #Shelter Island
> sample(c("BC","HMA","SDYC","SCM","SIM","SPHM","SYC","SYC","SHM"),3,
+ prob=c(146/2405,146/180,576/2405,160/2405,169/2405,522/2405,
+ 150/2405,382/2405,120/2405))
[1] "HMA"  "SDYC" "SPHM"
> #Moorings
> sample(c("COR1","ACH","COR2","LS","SI"),1,prob=c(110/547,170/547,
+ 69/547,154/547,44/547))
[1] "LS"
>
```

TOTAL NUMBER OF COMPLETED INTERVIEWS DESIRED: Approximately 200

Number of Completed Interviews Needed Per Marina/Mooring

> [Note that completed interviews needed is proportionate to size of strata and the number of marina/moorings in the strata. Divergence from 22 completed interviews is due to divergence of defined strata from the idealized multiple of 11.1% for strata population. This sampling scheme will result in a self-weighting stratified sample.]

1. Chula Vista Marina:	25
2. Coronado Yacht Club:	20
3. Cabrillo Marina:	25
Harbor Island West:	25
Sun Road Resort Marina:	25
4. Half Moon Anchorage:	22
San Diego Yacht Club:	22
Shelter Pointe Marina:	22
5. Laurel Street Mooring:	15
TOTAL SAMPLE SIZE	201

A simple method will be used at each chosen marina/mooring location to pick individual boats. This will be done by first looking up the number of slips/occupied moorings and picking every kth slip/mooring number or (slightly less desirable), where k is equal to the number of completed interviews needed divided by the number of slips/occupied moorings at the interview location. For example, in the Downtown/Harbor Island strata, we need to draw 25 respondents from Cabrillio Marina out of 450 slips, so that k in this case equals 18. In general, the calculation for k will not yield an integer number and it will be necessary to round k down.

It is necessary to draw more than that number from each of the chosen marinas/moorings due to non-response. With an assumption of a 50% response rate, it is necessary to draw a sample of twice the size of the number of completed interviews desired. This will be done by picking every kth respondent twice, using two different initial (randomly chosen) starting points between the 1st and the kth slip/owner number. If the marina keeps the list by owner name as opposed to slip location, the same approach can be applied to this list. For example, in the Cabrillio Marina example, pick a number between 1 and 18 such as 6 as the first observation for the sample and then pick every 18th slip/owner on the list so that the next number on the list picked is 24 and so on.. Then pick a second number such as 12 and pick every 18th observation on the list after that. Keep the two lists separate and go through all of the names on the first list before starting on the second. A random start point should be used when taking names from the second list. For surveys that are mailed, this approach is straightforward since owners will be chosen For surveys done in person, it may be necessary to substitute a boat (first on the right and then on the left), if the slip chosen is empty or the boater is not available after several attempts.

APPENDIX F2: SAN DIEGO BAY RECREATIONAL BOATER SURVEY

Marina or Yacht Club Name_____________________________ Slip Number ________

This survey should take about 15 minutes to complete. Thank you for your time and your interest in boating issues on San Diego Bay.

BOAT QUESTIONS

A1. What is the total number of boats that you keep at slips or moorings in San Diego Bay? _____**mean = 3.92**__*_ boats **st.dev. = 36.81; range: [0,500]**
***93% of respondents owned 1 boat; size of mean reflects fact that one respondent owned a fleet.**

All of the following questions refer to the boat at the location/slip chosen to participate in this study.

A2. Please fill in this table with your boat's characteristics:

Length of Boat (in feet)	Type of Boat (circle one)	Year Boat was Manufactured	How Many Years You've Owned Boat
____**35.71**___feet **(10.66)** **[18,114]**	Powerboat **40.22%** Sailboat **59.24%**	___**1980.55**___ **(11.72)** **[1930,2001]**	___**6.71**___years **(8.36)** **[.008,60]**

A3. About how often do you usually use your boat during each season? (Circle one for each season.)

Spring

More than once a week
20.77%
Once a Week
14.75%
Two or three times per month
30.05%
Once a month
24.04%
Less than once a month
10.38%

Summer

More than once a week
29.73%
Once a Week
22.16%

Two or three times per month
30.27%
Once a month
9.73%
Less than once a month
8.11%

Fall

More than once a week
20.33%
Once a Week
14.84%
Two or three times per month
34.07%
Once a month
19.23%
Less than once a month
11.54%

Winter

More than once a week
17.58%
Once a Week
10.99%
Two or three times per month
23.63%
Once a month
24.18%
Less than once a month
23.08%

A4. What is the main use of your boat? (Please circle one, and explain if other.)
Cruising Racing Daysailing Other (specify) ___________

A5. What type of antifouling system are you currently using on your boat?

A6. In each of the following seasons, about how many weeks go by between cleanings of your boat's hull?

Summer: ________weeks between hull cleanings

Fall: ________weeks between hull cleanings

Winter: ________weeks between hull cleanings

Spring: ________weeks between hull cleanings

A7. How many months go by between times that you apply bottom paint?

________ months between bottom paint application

A8a. Is it necessary to haul out your boat for any maintenance between the times that you replace the bottom paint? YES NO

A8b. If yes, what type of maintenance did you have done the last time your boat was hauled out but the bottom paint was not replaced?

ARE YOU AWARE THAT:

A9. The California Regional Water Quality Control Board for San Diego has found that there is a pollution problem involving copper in San Diego Bay? YES NO

IF YES, are you aware that:

A10. The California Regional Water Quality Control Board for San Diego has found that copper-based hull coatings on recreational boats contribute over 90% of the copper pollution? YES NO

A11. Copper coming off boats is toxic to marine organisms (other than those attaching to the hulls of boats), such as crabs, mussels, and sea urchins? YES NO

A12. The California Regional Water Quality Control Board for San Diego is legally required to reduce copper pollution so that water quality standards are no longer violated in San Diego Bay? YES NO

IF NO, then please read the following:

A13. The California Regional Water Quality Control Board for San Diego has found that copper-based hull coatings on recreational boats contribute over 90% of the copper pollution and that copper is toxic to marine organisms (other than those attaching to the hulls of boats), such as crabs, mussels, and sea urchins. The California Regional Water Quality Control Board for San Diego is legally required to reduce copper pollution so that water quality standards are no longer violated in San Diego Bay.

The rest of this survey deals with possible ways to reduce the amount of copper pollution coming from recreational boats in San Diego Bay.

A14. Are you familiar with any specific non-toxic bottom paints? YES NO

IF YES, which ones ____.

On a scale from 1 to 5 with 1 being not important, 2 being slightly important, 3 being somewhat important, 4 being very important and 5 being extremely important how would you rate the following factors in deciding whether to switch from a copper-based bottom paint to a nontoxic bottom paint?

		not important	slightly important	somewhat important	very important	extremely important
A18a.	Old copper paint is expensive to remove	1	2	3	4	5
A18b.	Non-toxic paint lasts longer	1	2	3	4	5
A18c.	Hull would need to be cleaned more often	1	2	3	4	5
A18d.	Would help make San Diego Bay cleaner	1	2	3	4	5
A18e.	Recommendation by boatyard	1	2	3	4	5
A18f.	Recommendation by underwater hull cleaner	1	2	3	4	5
A18g.	Boat would be easier to resell	1	2	3	4	5
A18h.	Required by marina/yacht club/mooring co.	1	2	3	4	5
A18i.	Required by law	1	2	3	4	5

B. BOTTOM PAINT CHOICE QUESTIONS

I am going to ask you several questions where you get to pick both your favorite and least favorite options for what bottom paint is applied to your boat the next time it is needed. First, I need to define some basic concepts that will help you compare the options.

DIFFERENT TYPES OF PAINT:

HIGH-COPPER: A toxic paint. (Cuprous oxide levels range from 40-76%.)
LOW-COPPER: A much less toxic paint. (Cuprous oxide levels range from 15-40%.)
EPOXY: A non-toxic paint. (Hard, durable bottom paint that can be scrubbed hard.)
SILICONE: A non-toxic paint. (Rubbery, slick surface. Fouling slides off easily.)

It is very likely that ten years from now all recreational boats in San Diego Bay will be required to be painted with a non-toxic paint.

ANTIFOULING COSTS:

There are four main costs of keeping your hull from becoming fouled:

(a) the cost of preparing your hull for painting,
(b) the cost of applying the bottom paint once the hull is prepared,
(c) how often the boat's hull needs new bottom paint, and
(d) how often your hull needs to be cleaned.

HULL PREPARATION COST:
There is often a one-time hull preparation cost if a new brand of bottom paint is applied. These costs vary depending on the formulation of the new paint and the similarity of the new paint to the one currently on the boat. Costs tend to be high if all existing paint must be removed and negligible when it is possible to paint over the existing bottom paint.
PAINT APPLICATION COST:
The different paints can have quite different application costs due to a variety of factors. Some of these relate to how long the bottom paint lasts or to the hull preparation cost.
PAINTING FREQUENCY:
Typically boats with high copper bottom paints have needed to be repainted once every 2 to 3 years. Proposed formulations of these paints and other types of bottom paint can extend the need to repaint to 4 to 6 years.
HULL CLEANING COST:
Boats with high-copper bottom paints usually need their hulls cleaned about 12 times per year. Boats with other types of bottom paint need to be cleaned about 18 times per year.

In each of the following questions, costs are given for four different available bottom paints that are labeled A, B, C, and D. These costs are for a 40-foot boat with an 11-foot beam. If your boat is smaller, your cost for the different options would be proportionately less and if your boat is larger, your costs would be proportionately more.

Please indicate at the bottom of each box your most preferred choice (in #1) and your least preferred choice (in #2) from among the four options offered (A-D).

B1. *Bottom Paints Available for Your Boat*

	A	**B**	**C**	**D**
Features of Bottom Paint	**High-Copper**	**Low-Copper**	**Epoxy (Non-Copper)**	**Silicone (Non-Copper)**
One-time hull preparation cost	$1,000	$2,000	$3,000	$0
Bottom paint application cost	$2,500	$3,000	$1,500	$2,000
How often you must repaint hull	Every 6 years	Every 2 years	Every 3 years	Every 4 years
How often you must clean hull	12 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**

B2. *Bottom Paints Available for Your Boat*

	A	**B**	**C**	**D**
Features of Bottom Paint	**High-Copper**	**Low-Copper**	**Epoxy (Non-Copper)**	**Silicone (Non-Copper)**
One-time hull preparation cost	$0	$1,000	$2,000	$3,000
Bottom paint application cost	$2,000	$2,500	$3,000	$1,500
How often you must repaint hull	Every 6 years	Every 2 years	Every 3 years	Every 4 years
How often you must clean hull	12 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**

Bottom Paints Available for Your Boat

B3.

	A	**B**	**C**	**D**
Features of Bottom Paint	**High-Copper**	**Low-Copper**	**Epoxy (Non-Copper)**	**Silicone (Non-Copper)**
One-time hull preparation cost	$2,000	$3,000	$0	$1,000
Bottom paint application cost	$3,000	$1,500	$2,000	$2,500

How often you must repaint hull	Every 3 years	Every 4 years	Every 6 years	Every 2 years
How often you must clean hull	12 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**

B4. *Bottom Paints Available for Your Boat*

Features of Bottom Paint	**A** **High-Copper**	**B** **Low-Copper**	**C** **Epoxy (Non-Copper)**	**D** **Silicone (Non-Copper)**
One-time hull preparation cost	$3,000	$0	$1,000	$2,000
Bottom paint application cost	$1,500	$2,000	$2,500	$3,000
How often you must repaint hull	Every 3 years	Every 4 years	Every 6 years	Every 2 years
How often you must clean hull	12 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**

B5. *Bottom Paints Available for Your Boat*

Features of Bottom Paint	**A** **Low-Copper**	**B** **Low-Copper**	**C** **Epoxy (Non-Copper)**	**D** **Silicone (Non-Copper)**
One-time hull preparation cost	$3,000	$2,000	$3,000	$0
Bottom paint application cost	$3,000	$1,500	$2,000	$2,500
How often you must repaint hull	Every 6 years	Every 6 years	Every 2 years	Every 3 years
How often you must clean hull	18 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**

2. Which of the options do you like least? (only one box)	**A.**	**B.**	**C.**	**D.**

B6. *Bottom Paints Available for Your Boat*

Features of Bottom Paint	A Low-Copper	B Low-Copper	C Epoxy (Non-Copper)	D Silicone (Non-Copper)
One-time hull preparation cost	$0	$2,000	$3,000	$0
Bottom paint application cost	$2,500	$2,500	$3,000	$1,500
How often you must repaint hull	Every 3 years	Every 4 years	Every 6 years	Every 2 years
How often you must clean hull	18 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (only one box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (only one box)	**A.**	**B.**	**C.**	**D.**

B7. *Bottom Paints Available for Your Boat*

Features of Bottom Paint	A Low-Copper	B Low-Copper	C Epoxy (Non-Copper)	D Silicone (Non-Copper)
One-time hull preparation cost	$3,000	$3,000	$0	$1,000
Bottom paint application cost	$2,000	$1,500	$2,000	$2,500
How often you must repaint hull	Every 4 years	Every 4 years	Every 6 years	Every 2 years
How often you must clean hull	18 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (only one box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (only one box)	**A.**	**B.**	**C.**	**D.**

B8. *Bottom Paints Available for Your Boat*

A **B** **C** **D**

Features of Bottom Paint	Low-Copper	Low-Copper	Epoxy (Non-Copper)	Silicone (Non-Copper)
One-time hull preparation cost	$2,000	$0	$1,000	$2,000
Bottom paint application cost	$3,000	$3,000	$1,500	$2,000
How often you must repaint hull	Every 2 years	Every 3 years	Every 4 years	Every 6 years
How often you must clean hull	18 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**

Bottom Paints Available for Your Boat

B9.

Features of Bottom Paint	A Epoxy (Non-Copper)	B Epoxy (Non-Copper)	C Silicone (Non-Copper)	D Silicone (Non-Copper)
One-time hull preparation cost	$3,000	$1,000	$0	$1,000
Bottom paint application cost	$3,000	$3,000	$1,500	$1,500
How often you must repaint hull	Every 6 years	Every 4 years	Every 2 years	Every 6 years
How often you must clean hull	18 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**

Bottom Paints Available for Your Boat

B10.

Features of Bottom Paint	A Epoxy (Non-Copper)	B Epoxy (Non-Copper)	C Silicone (Non-Copper)	D Silicone (Non-Copper)
One-time hull preparation cost	$0	$0	$1,000	$0
Bottom paint application cost	$2,500	$2,000	$3,000	$3,000
How often you must repaint hull	Every 6 years	Every 6 years	Every 2 years	Every 3 years

How often you must clean hull	18 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**

Bottom Paints Available for Your Boat

B11.

	A	**B**	**C**	**D**
Features of Bottom Paint	**Epoxy (Non-Copper)**	**Epoxy (Non-Copper)**	**Silicone (Non-Copper)**	**Silicone (Non-Copper)**
One-time hull preparation cost	$0	$1,000	$1,000	$1,000
Bottom paint application cost	$1,500	$2,000	$2,000	$2,500
How often you must repaint hull	Every 2 years	Every 3 years	Every 3 years	Every 2 years
How often you must clean hull	18 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**

B12. *Bottom Paints Available for Your Boat*

	A	**B**	**C**	**D**
Features of Bottom Paint	**Epoxy (Non-Copper)**	**Epoxy (Non-Copper)**	**Silicone (Non-Copper)**	**Silicone (Non-Copper)**
One-time hull preparation cost	$3,000	$2,000	$0	$3,000
Bottom paint application cost	$2,500	$3,000	$3,000	$1,500
How often you must repaint hull	Every 2 years	Every 3 years	Every 3 years	Every 4 years
How often you must clean hull	18 times (yearly)	18 times (yearly)	18 times (yearly)	18 times (yearly)
1. Which of the options do you like most? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**
2. Which of the options do you like least? (<u>only one</u> box)	**A.**	**B.**	**C.**	**D.**

C. Interest in Sea Grant Extension Demonstration Project Questions

C1. Are you interested in using or learning more about nontoxic bottom paints?

YES NO

C2. Would you like to receive a Sea Grant Extension Program brochure on nontoxic paints and other alternative antifouling methods? YES NO

The Sea Grant Extension Program will be conducting a field demonstration of nontoxic bottom paints on boats in the Shelter Island yacht basin during the next year. Would you be interested in:

C3a. In attending a field day for this demonstration? YES NO

C3b. In receiving more information about our project? YES NO

D. Boater Characteristic Questions

D1. How many years have you owned any boat kept at a slip or mooring in San Diego Bay? _____________years.

D2. Do you read any boating magazines or newspapers on a regular basis?
YES NO

D3. Do you ever get any information on boating from the Internet? YES NO

D4. What is your gender: FEMALE MALE

D5. What is your age? ______

D6. What is your highest level of education?

Some High School or less	Associates degree	Ph.D. degree
High School graduate	Bachelors degree	Professional Degree (J.D. or M.D.)
Some College	Masters degree	

D7. Which of the following broad categories best describes your total household income from all sources in 2001?: (Circle One)

$25,000 or less	$75,001-$100,000	$150,001-$175,000
$25,001-$50,000	$100,001-$125,000	$175,001-$200,000
$50,001-$75,000	$125,001-$150,000	$200,001 or more

D8. What is your zip code? ________________
OPTIONAL

Providing your contact information is entirely optional. If you are interested, the Sea Grant Extension Program would like to have your contact information so that we can:

-Send you the brochure, field day announcement and other project information.
-Contact you in about a year and a half to assess the effectiveness of our program.

All information will be compiled and reported as overall results. Individual information will not be released. If you have a particularly interesting comment, you may provide it in the space below, and we will ask your permission if we would like to quote it.

Your Name: ______________________________________

Address: ____
____

Phone: ____

And

Email address: _______________________________________
(put none, if none)

Comments:

Please return your survey in the enclosed self-addressed stamped envelope, to:

Leigh T. Johnson, Marine Advisor
Sea Grant Extension Program
University of California
5555 Overland Avenue, Building 4
San Diego, CA 92123-1200

F-3: Choice Model

F-3A: Choice Experiment Attribute Levels

8 distinct versions of the survey were distributed. There were 4 different versions of choice table questions, and half of each version contained a clause telling the subject that copper paints were likely to be banned in 10 years.

The series of 12 choice questions in each of the 4 choice table versions were created by randomly combining attributes from the following sets:

Paint Type
Traditional Copper
Low-Copper
Epoxy (Non-Copper)
Silicone (Non-Copper)

Hull Conversion Cost
$0
$1,000
$2,000
$3,000

Paint Application Cost
$1,500
$2,000
$2,500
$3,000

Paint Application Frequency
2 years
3 years
4 years
6 years

Hull Cleaning Frequency
12 times (yearly)
18 times (yearly)
18 times (yearly)
18 times (yearly)

F-3B: Choice Experiment Multinomial Logit Regression Results (Stata Output)

```
------------------------------------------------------------------------------------------
. mlogit  fav lowcu epoxy silic concost appcost pfreq

Iteration 0:   log likelihood = -3746.3024
Iteration 1:   log likelihood = -2970.2487
Iteration 2:   log likelihood = -2911.7591
Iteration 3:   log likelihood = -2910.0644
Iteration 4:   log likelihood = -2910.0617

Multinomial regression                            Number of obs   =       6664
                                                  LR chi2(6)      =    1672.48
                                                  Prob > chi2     =     0.0000
Log likelihood = -2910.0617                       Pseudo R2       =     0.2232

------------------------------------------------------------------------------
         fav |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
1            |
       lowcu |   .0310361   .1340663     0.23   0.817    -.2317289    .2938012
       epoxy |   .4516045   .1302667     3.47   0.001     .1962865    .7069225
       silic |   .4963304   .1281654     3.87   0.000     .2451308      .74753
     concost |  -.0007302   .0000328   -22.27   0.000    -.0007945   -.0006659
     appcost |  -.0008776   .0000612   -14.34   0.000    -.0009976   -.0007577
       pfreq |   .6218936    .022694    27.40   0.000     .5774142     .666373
       _cons |  -1.069599   .2051101    -5.21   0.000    -1.471608   -.6675909
------------------------------------------------------------------------------
(Outcome fav==0 is the comparison group)

. lrtest, saving(0)

. mlogit  fav lowcu epoxy silic totcost pfreq

Iteration 0:   log likelihood = -3746.3024
Iteration 1:   log likelihood = -2972.8133
Iteration 2:   log likelihood = -2914.3916
Iteration 3:   log likelihood = -2912.6822
Iteration 4:   log likelihood = -2912.6794

Multinomial regression                            Number of obs   =       6664
                                                  LR chi2(5)      =    1667.25
                                                  Prob > chi2     =     0.0000
Log likelihood = -2912.6794                       Pseudo R2       =     0.2225

------------------------------------------------------------------------------
         fav |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
1            |
       lowcu |   .0576938   .1338842     0.43   0.667    -.2047143     .320102
       epoxy |   .4621044   .1308307     3.53   0.000      .205681    .7185278
       silic |   .5188537   .1281426     4.05   0.000     .2676988    .7700087
     totcost |  -.0007572   .0000307   -24.69   0.000    -.0008173   -.0006971
       pfreq |   .6276077   .0226176    27.75   0.000     .5832781    .6719373
       _cons |  -1.339682   .1692035    -7.92   0.000    -1.671315   -1.008049
------------------------------------------------------------------------------
(Outcome fav==0 is the comparison group)

. lrtest
Mlogit:  likelihood-ratio test                            chi2(1)     =       5.24
                                                          Prob > chi2 =     0.0221

. mlogit fav lowcu nontoxic concost appcost pfreq

Iteration 0:   log likelihood = -3746.3024
Iteration 1:   log likelihood = -2969.8313
Iteration 2:   log likelihood = -2911.7264
Iteration 3:   log likelihood =  -2910.217
Iteration 4:   log likelihood = -2910.2152

Multinomial regression                            Number of obs   =       6664
```

```
                                                  LR chi2(5)      =    1672.17
                                                  Prob > chi2     =     0.0000
Log likelihood = -2910.2152                       Pseudo R2       =     0.2232

------------------------------------------------------------------------------
         fav |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
1            |
       lowcu |   .0306973   .1340311     0.23   0.819    -.2319988    .2933934
    nontoxic |   .4757545   .1226812     3.88   0.000     .2353038    .7162053
     concost |  -.0007279   .0000325   -22.40   0.000    -.0007915   -.0006642
     appcost |  -.0008777   .0000612   -14.35   0.000    -.0009976   -.0007578
       pfreq |   .6216609   .0226977    27.39   0.000     .5771742    .6661477
       _cons |  -1.070811   .2049208    -5.23   0.000    -1.472448   -.6691734
------------------------------------------------------------------------------
(Outcome fav==0 is the comparison group)

. lrtest
Mlogit:  likelihood-ratio test                        chi2(1)     =       0.31
                                                      Prob > chi2 =     0.5796

. mlogit  fav epoxy silic concost appcost pfreq

Iteration 0:   log likelihood = -3746.3024
Iteration 1:   log likelihood = -2969.9882
Iteration 2:   log likelihood = -2911.7877
Iteration 3:   log likelihood = -2910.0913
Iteration 4:   log likelihood = -2910.0886

Multinomial regression                            Number of obs   =       6664
                                                  LR chi2(5)      =    1672.43
                                                  Prob > chi2     =     0.0000
Log likelihood = -2910.0886                       Pseudo R2       =     0.2232

------------------------------------------------------------------------------
         fav |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
1            |
       epoxy |   .4284313   .0831533     5.15   0.000     .2654538    .5914088
       silic |   .4730776   .0793757     5.96   0.000     .3175042    .6286511
     concost |  -.0007301   .0000328   -22.27   0.000    -.0007943   -.0006658
     appcost |  -.0008788    .000061   -14.41   0.000    -.0009983   -.0007593
       pfreq |   .6220979   .0226763    27.43   0.000     .5776532    .6665426
       _cons |  -1.044797   .1746862    -5.98   0.000    -1.387175   -.7024182
------------------------------------------------------------------------------
(Outcome fav==0 is the comparison group)

. lrtest
Mlogit:  likelihood-ratio test                        chi2(1)     =       0.05
                                                      Prob > chi2 =     0.8167
```

APPENDIX G: REFERENCES

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