GENERATION AND MANAGEMENT OF RESIDUAL MATERIALS

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Petroleum Refining Performance

Generation and Management of Residual Materials

Petroleum Refining Performance 1991 Survey

Health and Environmental Affairs Department

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PREFACE

To improve the quality of the data collected, and its relevance to current developments, each year the American Petroleum Institute (API) reviews all data collected in this survey, and evaluates and revises, as necessary, the data collection forms and instructional materials. Consistent with this ongoing effort to promote the integrity of the survey findings and its utility to the industry, API has implemented a change in the terminology used in this survey. Beginning in 1990, API used the term "residual materials or residuals" instead of "wastes and secondary materials." This change in terminology reflects industry practices—the use of many of these materials as feedstocks or for recycling, reuse, and reclamation. This change helps to reconcile the utilization of these materials in our industry with the regulatory usage of the term "waste."

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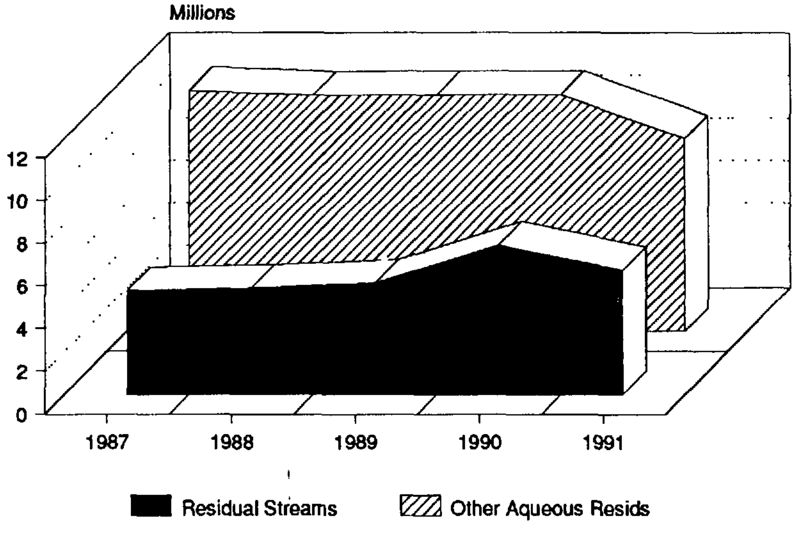
EXECUTIVE SUMMARY

In 1991, domestic refineries generated 14.8 million wet tons of residual materials. This population estimate was based on the American Petroleum Institute's survey on residual management practices. The survey has now amassed five years of consecutive data, with each cycle representing at least 70 percent of the refining capacity. This analysis of the 1991 data includes information from API's new question on pollution prevention activities, which when combined with the five years of data, provides a better understanding of trends in residual generation and management improvements.

The 14.8 million wet tons was the smallest quantity generated by the industry during the survey. The differences between the 1991 quantity and all previous years were statistically significant, even though the 16 million wet tons estimated for 1987-1989 were only slightly larger.

API makes a distinction between two classes of materials: there are 29 specific **Residual Streams** and another group of miscellaneous dilute materials, **Other Aqueous Residuals**. As illustrated below, Other Aqueous Residuals constitute the largest quantity of residuals. Rather than representing a typical industry generation pattern, however, these materials are generated by only several refineries that have deep-well injection capability. As displayed, the quantity of these Other Aqueous Residuals dropped in 1991.

Generation of Residual Streams and Other Aqueous Residuals: 1987-1991



Reductions were also observed in 1991 for several of the specific streams that make up the **Residual Streams category**. These include Pond sediments and Contaminated soils that dropped from the peak quantities reported in 1990, and the K-Wastes which have shown a more systematic downward trend over the survey period. The estimated quantity for several streams increased in 1991, including Spent caustics and the newly reported class of primary sludges (F037 and F038 listed wastes).

The trend analysis revealed distinct generation patterns for certain streams. For some, such as Spent FCCU and hydroprocessing catalysts, generation remained consistent over time. This would be expected since these streams are related to throughput. For others, like Spent caustics, the generation quantities have increased. It is believed that this reflects improved and more consistent reporting over the course of the survey.

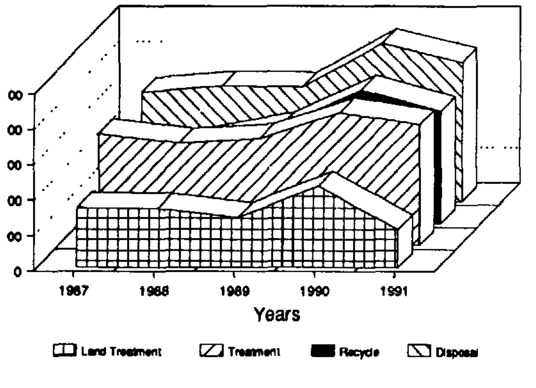
Another grouping of streams was based on the occurrence of pronounced, periodic spikes such as the peak quantities of pond sediments and contaminated soils generated in 1990. In these instances, larger quantities of waste equate to environmental progress, such as site remediation and construction of new process and residual management units.

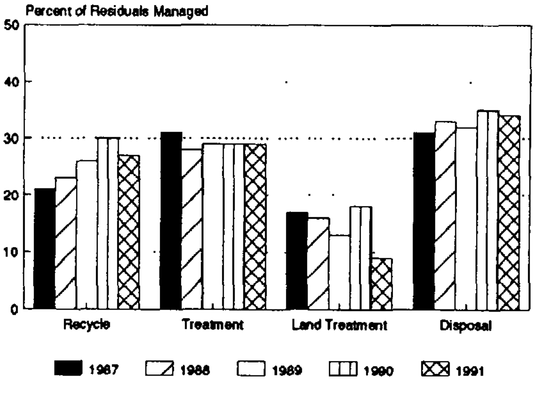
API separator sludge and DAF float belong to a group of streams where progressively smaller quantities were generated over time. These reductions reflect the industry's concerted effort to minimize generation of these streams, largely through pollution prevention activities. Indeed, refiners reported that a variety of pollution prevention activities accounted for a reduction of over 300 thousand wet tons of API separator sludge and DAF float. (Note that unlike the estimates for the population of refineries that are presented in this report, the pollution prevention information are not U.S. totals and only represent the amount reported by those refineries that responded to the pollution prevention question).

API's survey is the only ongoing effort to document pollution prevention activities across an entire segment of industry. In 1991, approximately half of the refiners responded to the pollution prevention question indicating that they had performed at least one source reduction or beneficial recycling activity. This accounted for 715 thousand wet tons of material. Pollution prevention activities were reported for 26 of the 30 residual streams. In an effort to promote technology transfer, API includes narrative summaries of the various methods used with each stream in its report.

In addition to these pollution prevention achievements, 1991 also witnessed improvements in how the refining industry manages non-aqueous residual materials. This is graphically depicted below, with the quantities handled by each technique on the left and a percentage display on the right.

Summary of Residual Management Practices: 1987-1991





As illustrated by the graph on the left, the peak quantities generated in 1990 affected some of the prevailing patterns or trends in residual management. For example, the industry's use of land treatment has diminished over the five year period, although 1990 witnessed a temporary increase when this technology was used to handle the residuals that resulted from one-time constuction and site remediation activities. Recycling, the most preferred handling technique in the waste management hierarchy, has increased since 1987, although 1991 saw a slight drop from the high noted in 1990. Treatment, which was not heavily relied on to manage the peak quantities generated in 1990, remained fairly constant, as did disposal.

The reduction in the use of land treatment and the increases in recycling reflect some of the management improvements instituted to meet the Resource Conservation and Recovery Act (RCRA) land disposal restrictions. As noted above, however, pollution prevention measures implemented by the industry significantly reduced generation of the K-wastes making compliance achievable. Thus, pollution prevention should be recognized as a crucial component of industry and regulatory plans to improve management of residual materials.

Section 1

INTRODUCTION

With this report for calendar year 1991, the American Petroleum Institute (API) has achieved its goal of collecting at least five years of data on residual material managed by domestic petroleum refineries. There are no plans to end this survey effort with this report; to the contrary, API is already collecting data for 1992 and 1993.

At this five-year mark, it seems appropriate to look back on the survey effort, and then, with this overview, proceed with the findings of the expanded analysis of the current data.

The five-year cycle for the survey was set for several reasons:

- to assure the availability of sufficient data to reliably characterize residual generation and management practices;
- to temper the interpretation of fluctuations observed between survey cycles; and
- to demonstrate the industry's commitment to voluntary efforts to monitor its environmental performance.

Reflecting some pragmatic concerns voiced by the refiners during the design phase of the study, these considerations have served as guideposts for the study. Refiners initially cautioned that trends would be difficult to determine because of the *unique considerations of each refinery.* Specifically, there are a variety of factors that influence residual generation: differences in the configurations of refineries, their age and capital improvements, geographic location, crude characteristics and product slates. Because of the multiplicity of interactions among these factors, refiners believe that efforts to control or influence residual management practices must give deference to site-specific considerations.

This five-year framework has likely enhanced the quality and utility of the data beyond the original plans for the survey. It has allowed successive refinements to be made in the survey questionnaire and data collection procedures, which, in turn, have improved the quality of the data collected, and the understanding of the data.

It is also important to note that there have been significant changes in the regulatory climate during the study interval. The survey was initiated in 1988, the height of the "command and control" approach to waste regulation, when more stringent prohibitions were being promulgated under the Resource Conservation and Recovery Act (RCRA). *Waste Minimization* was then the favored strategy for addressing waste generation.

By 1991, many of the proscriptive rules had become effective: there were three new streams listed as hazardous under RCRA and the new Toxicity Characteristic; land disposal restrictions precluded placement of hazardous wastes on the land without prior treatment to the Best Demonstrated Available Technology (BDAT); and *Source Reduction* was the preferred strategy for controlling waste generation.

As this report is published, a next generation of regulations is being contemplated: emphasis is placed on a more reasoned and holistic approach, wherein media-specific strategies are integrated, and site-specific flexibility is being discussed. *Pollution prevention,* which encompasses waste minimization and source reduction, is now the accepted term for waste management improvements.

The petroleum industry's environmental concerns, compliance strategies and management approaches have likewise evolved over the study period. Indeed, this survey is now part of a larger effort by the industry to publicly account for its environmental practices. The STEP program--a Strategies for Today's Environmental Partnership--was developed to implement API's guiding principles in 1991. STEP calls for a series of data collection efforts to enable a self-assessment of the industry's environmental practices.

Because the survey always included a reporting component, API viewed the effort as fulfilling its responsibility to promote technology transfer--one of the tenets of an effective waste minimization program. The survey reports, with the descriptive summaries of innovative activities undertaken by refiners, served as a vehicle to disseminate this information.
A secondary benefit, not recognized at the outset, is that the survey instrument itself has become an important tool for the industry, providing direct technical guidance to refiners on measuring residuals generated and standardizing accounting of their subsequent management.

And again, this effort paved the way for other research. The success of the survey helped the industry to mount several projects that promote innovative techniques, such as the design of a new crude unit that minimizes multi-media releases.

The availability of this survey data has already helped the industry to engage in more meaningful dialogue about its practices with community and special interest groups, local and Federal regulatory agencies. API anticipates that these activities will increase with the issuance of this report and the industry's more comprehensive analysis of the data on the residual generation patterns, and the quantitative profile of how the industry is meeting the management challenges of the nineties.

Section 2

METHODOLOGY

For 1991, as with all previous years, the survey employed a census design. A listing of the 183 operating refineries was developed from the Department of Energy's *1991 Petroleum Supply Annual.* Survey materials were mailed in August, 1992--one month earlier than the typical September mailing date. As with previous years, the six week interval allowed for form completion was extended to increase the response rate. Contact was maintained with all refineries during the field administration, with three follow-up calls placed to refineries to encourage response and through a "HELP-line" staffed by a refining expert.

The questionnaire was revised for 1991 to reflect regulatory changes that affected the classification of refining residuals and to gather information on pollution prevention. The analytic procedures were also updated to improve the estimation for 1991, and to expand the analysis of the data beyond the simple summary statistics previously generated. The sections that follow describe the revisions of data collection forms and of the analytic procedures used to create the population estimates.

DATA COLLECTION FORMS

API's survey questionnaire for 1991 included nine short-answer questions focused on refinery characteristics and a series of "data sheets"— one-page forms that collect empirical information on the quantities of residual materials[1] generated and how they are managed. There were 30 data sheets for 1991. On each, "inputs" of residual materials are balanced against "outputs." Inputs include the Quantities Generated plus Treatment Additives and the Net Removed from Storage (i.e., the total amount of material removed from storage minus the amount placed into storage) and constitute the "Total Quantity Managed." As illustrated below, this is balanced according to the waste management hierarchy by the quantities of waste *recycled, treated, or disposed.*

Quantity Generated + Treatment Additives + Net From Storage = **Total Quantity Managed**

Total Quantity Managed = Quantity Recycled + Quantity Treated + Quantity Disposed

API used a two-page format for the data sheets in 1991. Rather than provide a "Code sheet" to which refiners had to refer for the various recycle, treatment and disposal codes, these codes were printed on the back of the preceding page in a different color. Survey participants no longer had to flip back and forth to code management practices, an activity that increased the respondent burden, and increased the likelihood of data coding errors.

[1] Beginning with publication of the Final Report for 1990, API has used the term "residual materials or residuals" to refer to what had previously been called "wastes and secondary materials." This change in terminology reflects industry practices--the use of many of these materials as feedstocks or for recycling, reuse, and reclamation. This change helps to reconcile the utilization of these materials in the petroleum industry with the regulatory usage of the term "waste."

The questionnaire was provided in both hard copy form and on an automated disk, written using Clipper, a commercially available compiler for dBase. A copy of the data collection form is presented in Appendix A.

Several changes in the forms were implemented for 1991:

- new questions on the impact of the *Toxicity Characteristic (TC)* were added to the short answer questions about the refinery characteristics;
- the listing of refinery streams was modified to incorporate the newly *listed "F wastes" under RCRA*.
- a *Pollution Prevention* question was added to each data sheet.

Two questions were developed on the **Toxicity Characteristic**. The first requested information on the amount of wastewater that failed the Toxicity Characteristic Leachate Procedure and its disposition. The second question focused on the amount of residuals considered "solid waste" under RCRA that was characteristically hazardous. (See Questions 8 and 9 in Appendix A.)

In 1990, three new streams were designated as **listed hazardous wastes** under RCRA:

- F037 - Primary sludge (Gravitational separation)
- F038 - Primary sludge (Physical/chemical separation)
- F039 - TSD Leachate

Data on these residuals had previously been captured by the survey, aggregated with other residual materials. Consequently, in addition to adding these three streams to the existing listing of 28 streams, all references to these residuals were deleted from the description of other residuals. Because **Other Separator Sludges** (API code 105) was now subsumed by F037 and F038, there remained a total of 30 waste streams. This listing of streams is presented in Table 1.

As the footnote to Table 1 suggests, the intent of the survey was to capture information on only residual materials—not wastewater that is directly treated and discharged under a NPDES permit or discharged to a POTW.

Table 1
Refining Residual Streams

Category	Constituents
Aqueous residuals	Biomass High pH/low pH waters Oil contaminated waters (not wastewaters)* Spent Stretford solution Spent sulfide solution TSD Leachate (F039)*** Other aqueous residuals NOS**
Chemicals/inorganic residuals	Spent acids Spent caustics Residual amines Other inorganic residuals NOS**
Contaminated soils/solids	Contaminated soils/solids Heat exchanger bundle cleaning sludge*** Residual coke/carbon/charcoal Residual/waste sulfur Other contaminated solids NOS**
Oily sludges/other organic residuals	API separator sludge*** DAF float*** Leaded tank bottoms*** Nonleaded tank bottoms Pond sediments Primary sludge (F037)*** Primary sludge (F038)*** Slop oil emulsion solids*** Waste oils/spent solvents Other oily sludges/organic residuals NOS**
Spent catalysts	Fluid cracking catalyst Hydroprocessing catalyst Other spent catalysts NOS**
Other residuals	Other wastes NOS**

* Does not include NPDES or POTW wastewaters.
** Not otherwise specified.
*** RCRA-listed hazardous wastes for petroleum refining.

The new **pollution prevention** question replaced the questions previously used to capture information on *source reduction* and *resource recovery*. Each year refiners have had difficulty applying the definition of source reduction to industry practices, in particular, distinguishing these from other improvements in residual management practices. To enable refiners to report beneficial recycle of residual materials *out-of-process on-site or by other users off-site*, in 1990 API developed a new question to obtain information on Resource Recovery activities. This question was placed immediately *before* the Source Reduction question, in an effort to force respondents to make a distinction between various beneficial activities, some of which are considered to be waste minimization, and others that are regarded as source reduction.

This strategy improved the reporting of this information, but did not totally resolve activity classification errors.

API believes that source reduction and beneficial recycling of materials are both critical elements in industry efforts to manage residuals. Moreover, API's survey experience suggests that the distinction between the two, or prioritization of one over the other, is not necessarily meaningful to refiners. Rather than perpetuate this somewhat arbitrary distinction, and as part of its continued effort to increase refiners' awareness of these activities and improve the quality of the data collected, API combined the two questions. The reporting format previously used for the source reduction question was retained, but the activity categories were expanded to include four new recycle codes. The question was labeled *Pollution Prevention* since this concept embraces both source reduction and beneficial recycling. Placed on each data sheet where refiners are asked to perform quantitative calculations, spaces were provided for up to three activities. The pollution prevention activity codes were placed on the facing worksheet. Both the question and codes are presented in Figure A.

Figure A
Pollution Prevention Question and Code Categories

POLLUTION PREVENTION

Did your refinery initiate any activities, change any practices or modify any equipment that **DECREASED** the amount of this waste stream generated or requiring disposal capacity in 1991?

☐ No

☐ Yes - Enter amount reduced, ________wet tons, circle the appropriate waste prevention method code below and provide a brief description of the method used:

Code	Description:
1 2 3 4 5 6 7 8 9 10	Activity 1. Year 19 __ __ ________________________________ ________________________________

POLLUTION PREVENTION CODES

1 = Equipment or Technology Modifications
2 = Procedure Modifications
3 = Reformulation or Design of Products
4 = Substitution of Raw Materials
5 = Improved Housekeeping, Training, or Inventory Control

IN-PROCESS RECYCLE
6 = In refining process units (e.g., crude unit; coker; desalter)
7 = Recovering oil (& dewatering) by filter pressing/centrifugation
8 = Other recycle

OUT-OF-PROCESS RECYCLE
9 = Reuse/reclamation
10 = Other

DATA ANALYSIS

The data verification and estimation procedures for 1991 were similar to those used previously. Data verification included 28 automated consistency checks for the variables on each data sheet, as well as final range checks across respondents and comparisons with the data previously submitted by the respective refinery. In cases that were identified in the edit, the data were verified by direct contact with the facilities to ensure its accuracy.

For each survey year, API develops an estimate of residuals generated by the entire industry based upon information submitted by survey respondents.[2] Implicit in this approach are the assumptions that the factor(s) influencing waste generation for respondents do not differ from those for non-respondents.

Regression analysis was used to estimate the residual quantity generated by the industry. In previous years, the regression model was based on all residual streams. For 1991, **Other Aqueous Residuals NOS** (Not Otherwise Specified) was not included in the model because it was the stream with the most aberrant responses. That is, few refineries report generating this stream, but those who did, reported extremely large quantities that were disposed by injection in wells. In all previous cycles, these cases had been identified as statistical outliers and were handled differently during model development. However, in 1991, this stream was handled separately throughout the modelling and estimation procedure as described in Appendix B.

Data on refinery characteristics (e.g., operating capacity, age, sewer system) was analyzed to evaluate the effect of the different factors on residual generation at a refinery. Scatter-plots were used to explore relationships between residual generation and the factors thought to be affecting it. Correlation analysis was performed and as in previous years, operating capacity of a refinery was found to be most significantly correlated with residual generation.

Scatter-plots were also used to quantify the form of capacity that best captured its relationship with residual generated. Regression models using different forms of capacity and residual quantity generated were evaluated based on performance criteria like R^2 and Root Mean Squared Error. Evaluation was also based on how closely model assumptions on normality of residuals and homogenous variance of residuals were followed.

In 1991, six outliers were identified during the modelling procedure. Outliers are influential observations that do not follow the general trend of the data and thus deleting them from the model results in a better fit. The six outliers were excluded only from the model used for estimating residual quantity generated by the non-respondents but were included at all other stages of the estimation procedure.

After examining regression models, scatter plots and correlations, it was found that the best relationship was between capacity and square root of total residual quantity generated at a refinery. Therefore, the regression model used for 1991 was of the form:

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[2] A more technical summary of the estimation procedures is included in Appendix B.

$$\sqrt{Total\ Generated\ Quantity} = a + b(Capacity)$$

or

$$Total\ Generated\ Quantity = [a + b(Capacity)]^2$$

where a and b were estimated based on the data from the 107 responding refineries that were not statistical outliers. Because of the square-root transformation, this model yields a biased estimate of the residual quantity generated and a bias correction factor has to be applied. The regression model was then used to estimate the total residual generated by each non-respondent by (1) inputting its capacity into the model; (2) squaring the result; and, (3) applying a bias correction factor so that the final estimate is unbiased.

To estimate the total amount of residual materials generated in 1991 for all (183) of the U.S. refineries, estimates for the 70 non-respondent refineries were combined with: 1) the data obtained from the 113 survey participants (including the six outlier facilities); and 2) the quantity of **Other Aqueous Residuals** estimated for the population of refineries. This is illustrated in the first row of the flow chart presented in Figure B. All residual generation and management data shown in this report are estimates for all 183 refineries.

After deriving the total quantity of generated residual, calculations were performed to estimate the generation quantities for each of the 29 residual streams. A summary of the procedure used is as follows:

1) The total reported quantity of residuals for each stream was determined by summing the generated quantities from all respondents.

2) The relative contribution of each stream to the total reported quantity was obtained by dividing the individual residual stream generation quantity calculated in (1) by the total quantity of residuals for all 29 streams generated by respondents.

3) Each proportion calculated in (2) was multiplied by the total estimated residual quantity for all non-respondents to get residual quantities, by stream, for non-respondents.

4) Estimated generated quantity for a stream was obtained by summing the corresponding respondent and non-respondent quantities from (1) and (3). This is depicted in the second row of the flow chart.

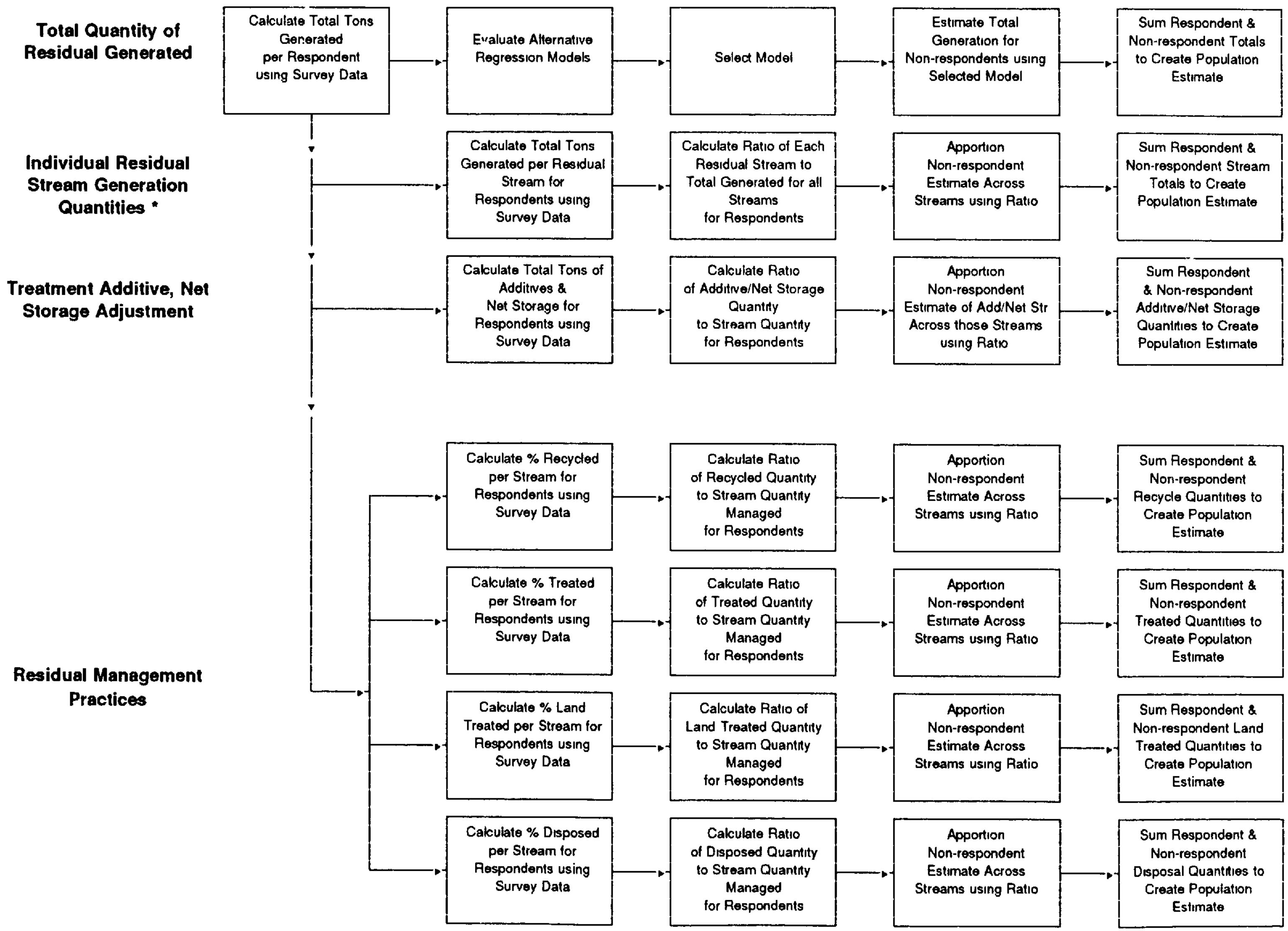
To obtain the managed quantity of residuals, the proportion of treatment additives and net quantity from storage to generated quantity in each stream was calculated. (Shown in the third row of Figure B.) These proportions were then multiplied by the non-respondent generated quantity for a stream to get estimated amounts of treatment additives and net from storage. Thus, the managed quantity of residuals was calculated by summing (a) generated quantity,

(b) treatment additives and (c) net from storage for respondents and non-respondents. A detailed explanation of the above procedure and that used for estimating recycled, treated and disposed amounts is given in Appendix B. The last four rows of the flow chart illustrate how the management estimations are performed.

Also, variances for the total estimated generated quantity and individual stream quantities were calculated. Using these variances, approximate 95% confidence intervals for the individual stream quantities were obtained.

Since 1991 is the fifth year of the Refining Residuals survey, longitudinal data was available to conduct a trend analysis. For each stream, the estimated generated quantity and its 95% confidence interval was plotted for all years. Significant differences in residual quantities over years can be evaluated by determining any overlap in the confidence intervals from one year to another.

Figure B - Statistical Estimation Procedures



* For this chart, STREAM refers to the 29 individual streams included in the analysis.

Section 3
RESULTS

RESPONSE RATE

In 1991, 113 refineries participated in the survey. This represented 62 percent of the population of 183 refineries, and accounted for 73 percent of the domestic crude refining capacity. This was the second highest response obtained, and continues the industry's achievement of at least 70 percent of the refining capacity participating in each survey cycle.

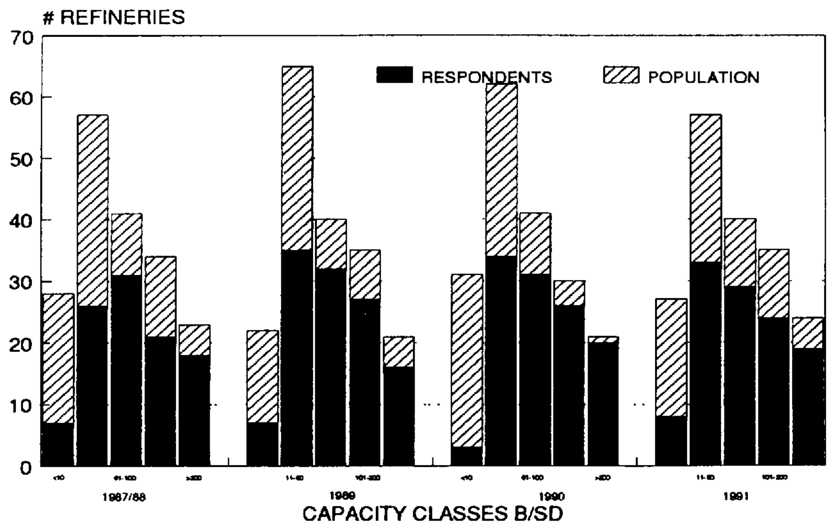
Of the 113 respondents, 70 had participated in all five years, which provided a sizeable cohort for covariance calculations. This was, however, 14 less than the 84 that had participated in all of the previous four surveys. The turnover in participants--particularly in this group of refineries that regularly respond--serves as a reminder that the population of refineries varies from year to year. Even though the total number of operating facilities has remained 183 for the last few years, each year there have been some closings and reactivations. In 1991, six refineries owned by majors, five of which had participated in each previous survey, either closed, converted to asphalt plants or marketing terminals (i.e., no longer met the inclusion criteria for this survey) or were sold. During the year, five other refineries were reactivated. As will be seen in the following discussion of refinery characteristics, the overall turnover of approximately 22 percent exerted some subtle, but detectable changes on the sample characteristics.

RESPONDENT CHARACTERISTICS

The 113 respondents reported an *operating capacity* of 12,073,851 barrels per stream day (b/sd). The total amount of crude charged in 1991 was 3,848 million barrels.

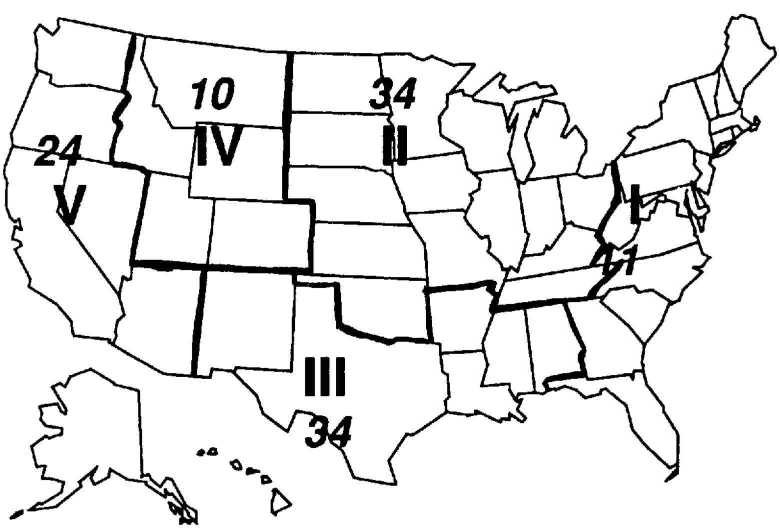
The profile of respondents by *capacity class* was very similar to that observed previously (See Figure C). There was an increase in the number of small refineries participating in the survey. Also, the distribution of operating refineries shifted slightly from 1990, with fewer in the 51-100 b/sd class, and several more in the 100-200 b/sd group.

Figure C
Number of Respondents by Capacity Group



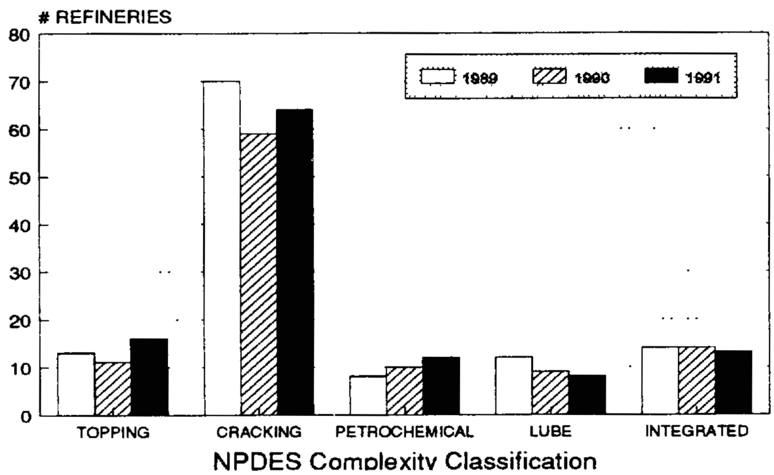
The distribution of refineries by *location* changed in 1991, departing from the direct relationship previously noted between the total number of refineries in each U.S. Department of Energy's Petroleum Administration for Defense (PAD) district and the number of refineries participating in each region. As shown in Figure D, the 34 respondents from PAD II (the third largest district) equalled the 34 refineries in the Texas/Louisiana region (PAD III), the district with the most operating refineries. The number of participants in PAD V increased by two, while one less refinery responded from PAD IV.

Figure D
Distribution of Respondents by Location



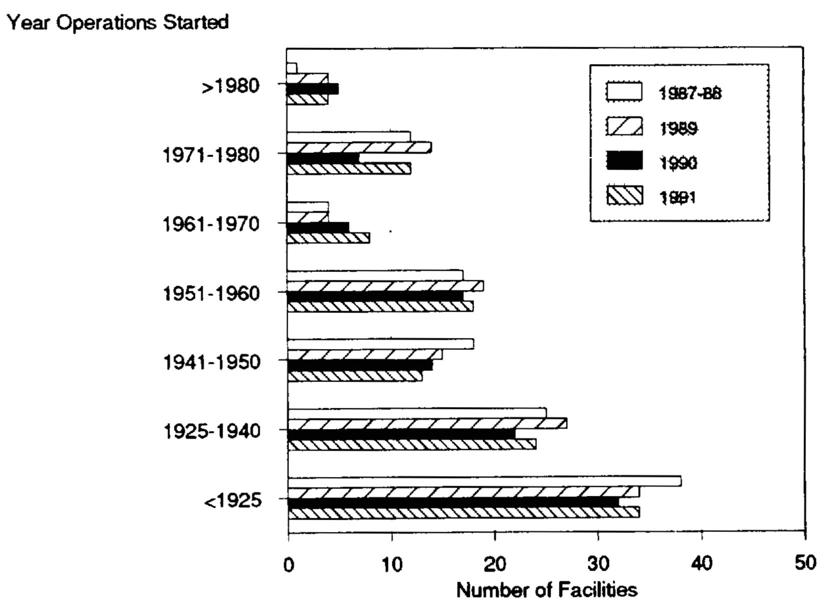
API uses the NPDES permit classifications to categorize the *complexity* of the refineries. Consistent with overall distribution of refineries, cracking facilities continued to predominate in 1991 (See Figure E). Several more topping facilities responded this year, a likely occurrence when one considers the increase in participation observed in the smallest capacity class.

Figure E
Distribution of Respondents by NPDES Complexity Classification



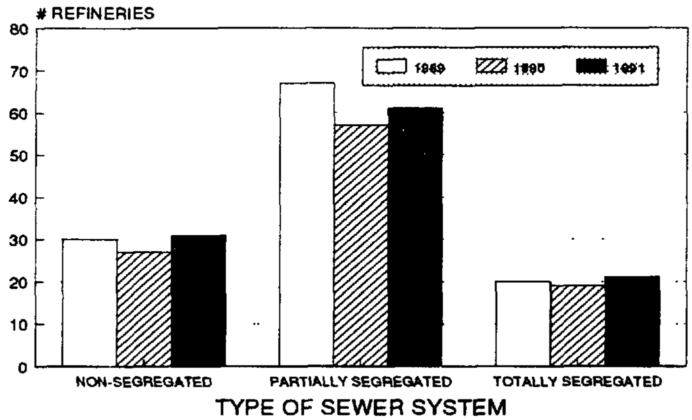
The data collected on the *age* of the refineries are presented in Figure F. The subtle differences across survey years reflect the turnover in the respondent sample. The largest between-year differences occur in refineries built between 1971-1980, relatively new facilities. The largest group continues to be the oldest, approaching 70 years in operation, since they were built before 1925.

Figure F
Distribution of Respondents by Refinery Age



As illustrated in Figure G, the data collected on the type of *sewer system* does not seem to change from year to year, with 73 percent of the refineries segregating some, if not all storm waters from process waters. The slight increases in the number of refineries with partially segregated sewers appears to reflect the increase in the response rate, rather than a shift among facilities from one sewer system type to another.

Figure G
Distribution of Respondents by Sewer Type

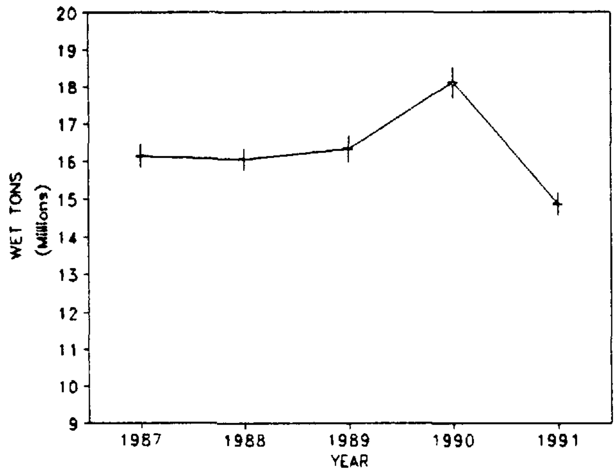


The survey also collected information on *RCRA Permit Status*, requiring participants to indicate their status, either as 1) Generators only with no RCRA permit required; 2) Interim Status (Part A filed) or 3) RCRA permit issued. The refineries were rather evenly distributed, with 38 that were only generators, 38 that had received their permit, and 29 facilities that were in Interim Status.

RESIDUAL GENERATION

The total amount of residual materials generated in 1991 by the 183 U.S. petroleum refineries was estimated to be 14.8 million wet tons--the smallest quantity estimated during the five years of this survey. As shown in Figure H, this was 2.9 million wet tons less than the 18.2 million wet tons generated in 1991 and substantially less than generated in 1987-1989. As the vertical variance bars on the estimates indicate, the difference between 1991 and 1990 was statistically significant (i.e., the vertical bars do not overlap). The amount of residuals generated in 1991 and 1990 differed significantly from the quantities estimated for 1987-1989, which, as shown by the overlap in the variance bars, were comparable.

Figure H
Residual Generation in the Petroleum Refining Industry: 1991 - 1987



What happened in 1991? The greatest change was observed in the generation of **Other Aqueous Residuals**, a stream generated by only a few refiners, but one that has accounted for more than two thirds of the residuals generated in each survey cycle. The amount of **Other Aqueous Residuals** generated in 1991 was over 2 million wet tons less than 1990. This reduction reflects movement by some refiners away from deep well injection of residuals, with concomitant changes in the pretreatment and handling of the dilute residuals that had been suitable for injection. In 1991, four refineries reduced their reliance on deep well injection and are planning total phase-out of this disposal technique. Another refinery obtained a "no-migration" permit for their Class I well, having demonstrated that continued use of the well presents no environmental hazards.

At the same time, the industry witnessed an increase in the amount of **primary sludges** generated, the newly listed "F wastes" under RCRA. Two hundred thousand additional wet tons of these materials were estimated as being generated in 1991. It is unclear whether this represents a true increase in generation, an artifact of the new classification and reporting requirement (e.g., the "F wastes" were reported for the first time in 1991 as individual streams), or even a peak in generation that resulted from refiners making an effort to remove these materials before more costly management practices are required when LDR requirements become effective. Comparing the differences in the quantities of API Separator Sludge and DAF Float generated between 1990 and 1991, with the quantities of Primary Sludge reported in 1991, however, make it clear that with few exceptions, refiners did not reclassify K-wastes as F-wastes. The exceptions included a refinery that had previously reported the residual from an Induced Air Flotation unit as DAF float and was now correcting their reporting to show that this material was a Primary Sludge. In another case, a refinery reported taking an API Separator out of service and replacing it with an IAF unit (again appropriately reported as a Primary sludge).

The remaining 26 streams had an overall decrease of close to 1.4 millions wet tons, as illustrated in Table 2.

Table 2
Estimate of All Residuals Generated by the U.S. Refining Industry: 1991
(thousands of wet tons)

Residual Category	1991	1990	1989	1988	1987
Aqueous residuals NOS	9,036	11,107	11,100	11,076	11,296
RCRA F Wastes	327	97*	144*	104*	79*
Remaining 27 Residual Streams	5,482	6,902	5,067	4,864	4,769
Total	14,845	18,106	16,311	16,044	16,144

*The quantities for 1987-1990 for Primary Sludge were based on the estimates for "Other Separator Sludges," a stream that was subsumed in 1991 by the Primary sludge streams.

This pattern of an increase in one type of residual being offset by decreases in other streams is noted in Table 3, which presents the annual data for the 29 individual streams.

Increased quantities were estimated for the two largest streams, **spent caustics** and **biomass.** For both of these streams, the 1991 quantities were the largest ever generated. Other streams with increases were relatively low quantity streams: **residual coke/carbon/charcoal, residual amines, oil contaminated water** (not wastewater) and **spent sulfite solution.**

The largest decrease was noted for **pond sediments** which plummeted from its 1990 peak of over one million wet tons to 372 thousand wet tons. This was a return to a level comparable to the pre-1990 high when many refiners reported closures of surface impoundments that created the spike in the generation curve. Although the quantity of **Contaminated soils /solids** also dropped from the peak in 1990, this stream remained the third largest. Refiners continued to report substantial one-time generation quantities of this stream: for 1991, over 400 thousand wet tons or 67 percent of the total amount of **Contaminated soil/solids** generated resulted from "abnormal" events. Common knowledge of the industry's ongoing site remediation activities and construction to update refining process units corroborates this generation pattern.

Table 3
Estimate of Residual Materials Generated by the U.S. Refining Industry: 1991
(thousands of wet tons)

Residual stream	1991	1990	1989	1988	1987
Spent Caustics	909	889	716	656	675
Biomass	855	782	642	786	757
Contaminated soils/solids	809	920	512	240	165
DAF float	406	553	496	655	652
Other inorganic residuals NOS	397	451	440	213	325
Pond sediments	372	1,017	313	266	337
Other residuals NOS	339	352	325	412	203
API separator sludge	210	251	419	355	400
FCC catalyst or equivalent	204	198	182	193	173
Primary sludge (F038)	177				
Slop oil emulsion solids	165	291	272	224	208
Residual coke/carbon/charcoal	138	92	129	67	43
Residual amines	136	75	51	14	13
Primary sludge (F037)	130				
Nonleaded tank bottoms	109	194	161	129	216
Spent acids	88	336	8	149	126
Oil contaminated waters (not wastewaters)	67	8	29	36	28
High pH/low pH waters	54	105	91	138	144
Other oily sludges/organic residuals NOS	54	53	47	61	38
Other contaminated soils NOS	37	69	53	68	82
Hydroprocessing catalysts	32	31	36	36	40
Spent Stretford solution	25	29	42	49	35
Other spent catalysts NOS	23	39	33	37	33
Residual oils/spent solvents	21	115	31	7	4
TSD Leachate (F039)	20				
Residual sulfur	19	35	52	22	17
Spent sulfite solution	9	1	8	40	42
Heat exchanger bundle cleaning sludge	3	13	2	5	3
Leaded tank bottoms	1	3	4	8	9
Other separator sludges	NA	97	114	104	79
Total	5,809	6,999	5,508	4,968	4,868

The decreases in the RCRA "K wastes" also contributed to the overall reduction in generation quantities. **DAF float** and **slop oil emulsion solids** both dropped by over 100 thousand wet tons, to 406 and 165 thousand wet tons, respectively. **API separator sludge** experienced a more modest decrease, but had already undergone some successive, substantial reductions.

While the quantities of **heat exchanger bundle cleaning sludge** and **leaded tank bottoms** were quite small, they nonetheless represented reductions of one third or more. As will be discussed later in this report, many refineries attributed these decreases to source reduction activities.

Sizeable reductions were also observed for **spent acids**, **nonleaded tank bottoms**, **other contaminated soils** and **residual oils/spent solvents**, streams that have some similarities in reporting patterns, but more interesting differences. As shown in Table 4, **nonleaded tank bottoms**, **other contaminated soils** and **residual oils/spent solvents** were reported by at least 59 refineries, a relatively high rate for this survey. **Spent acids**, on the other hand, was only reported by 20 refineries. What is interesting is that the decrease for **spent acids** and **residual oils/spent solvents** reflects a change in generation rate by a only a few of the refineries participating in the survey, while the reductions in the other two streams appears to reflect a more systematic change by the group of refiners reporting each of these streams.

These frequency counts provide corollary information to the estimated quantity of residuals by the population of refiners, suggesting that there are *patterns* of generation. From Table 4 it is clear that no individual stream is generated by all refiners in any year. Yet some streams are generated by individual refiners every year, while other refiners generate these streams every other year, less frequently, or not at all. Because residual streams are generated periodically, no single year of data can provide a reliable snapshot of industry practices. Even with several years of data, effort must be exerted to control for this source of variability in the estimated quantity of residual material.

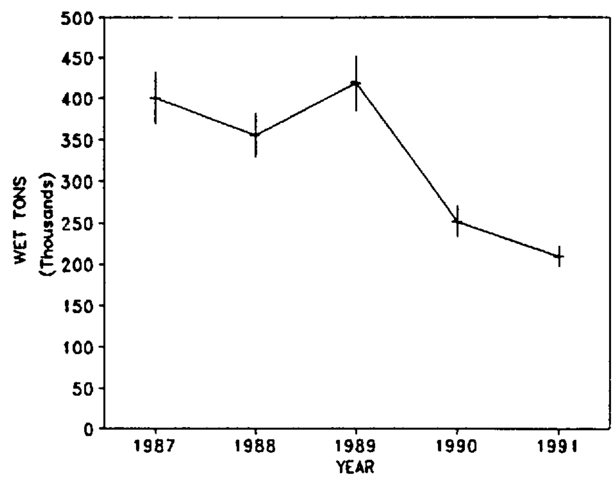
Table 4
Number of Refineries Reporting Each Stream

Residual stream Total number of refineries participating	1991 113	1990 103	1989 117	1988 115	1987 115
Contaminated soils/solids	90	87	88	77	77
Other residuals NOS	83	85	89	85	92
FCC catalyst or equivalent	76	79	84	86	85
API separator sludge	76	85	93	94	91
Nonleaded tank bottoms	69	72	72	75	72
Spent caustics	69	66	70	77	79
Residual oils/spent solvents	65	56	56	61	52
Other spent catalysts NOS	63	57	60	60	62
Other inorganic residuals NOS	62	65	73	73	77
Primary sludge (F037)	59				
Other contaminated soils NOS	59	56	61	71	70
Hydroprocessing catalysts	57	52	65	60	57
Residual coke/carbon/charcoal	55	50	51	47	48
Biomass	45	44	44	45	47
DAF float	44	50	47	50	53
Heat exchanger bundle cleaning sludge	43	51	49	48	49
Other oily sludges/organic residuals NOS	43	42	49	47	49
Residual sulfur	43	37	42	47	41
Slop oil emulsion solids	32	35	38	43	47
Residual amines	32	27	38	36	32
Pond sediments	25	34	31	29	26
Leaded tank bottoms	20	27	31	37	38
Spent acids	20	24	18	23	20
Other aqueous residues NOS	14	11	14	12	13
Primary sludge (F038)	14				
Oil contaminated waters (not wastewaters)	10	10	14	10	14
Spent Stretford solution	6	7	11	13	12
High pH/low pH waters	4	11	11	12	14
Spent sulfite solution	3	1	2	1	1
TSD Leachate	3				
Other separator sludges	NA	19	22	20	15

To gain a better understanding of the changes that have been observed in the generation rates, API performed two ancillary analytic procedures: a trend analysis was undertaken to identify statistically significant differences in the generation rates for individual streams between survey years; and, a covariance analysis was performed on the subset of refineries that had participated in all five years of the survey.

For the trend analysis, the approximate 95 percent confidence interval for each stream estimate was plotted and reviewed. The determination of statistically significant differences relies on a simple visual inspection of the graph: when the variance bars overlap, it is assumed that there is no statistically significant difference in the generation rates; conversely, when the bars do not overlap, the difference is considered to be statistically significant. The graph for API Separator Sludge (KO51) is presented below to illustrate the graphic output for each stream.

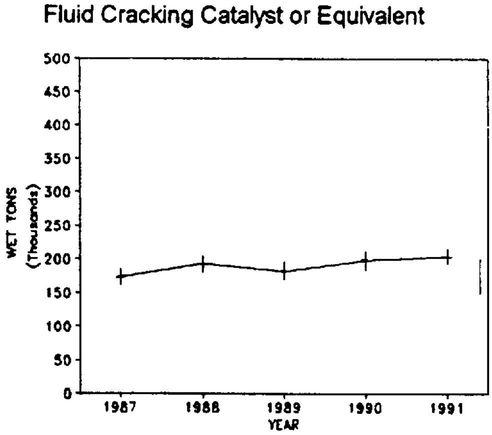
Figure I
Trend Analysis Plot for API Separator Sludge

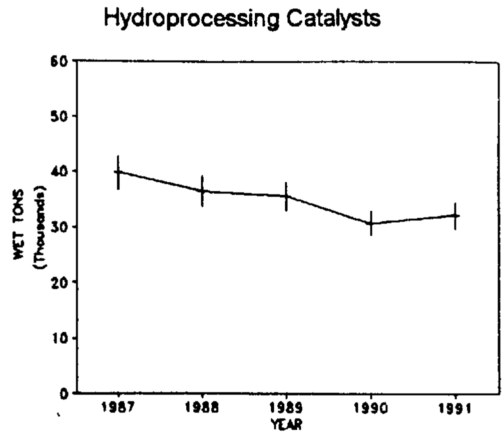


This graph shows that from 1987 to 1989, the generation of API Separator Sludge varied between years, but no statistically significant difference was observed. In both 1990 and 1991, the amount generated dropped substantially, with the difference between 1990 and the three previous years being statistically significant. The amount generated in 1991 was also significantly different from all previous years. As the width of the error bars (Confidence interval) indicates, the error in the estimate has also diminished over time, with error for 1991 being the smallest.

Review of these trend graphs for each stream has provided some interesting observations about the variability in the generation rates across time. The streams that remained fairly static, as shown below, were the catalysts: **FCCU catalyst or equivalent** and **hydroprocessing catalysts**. Use of catalysts by the industry is largely a function of throughput, which has remained fairly constant over the survey period.

Figure J
Generation Trends for FCCU and Hydroprocessing Catalysts





For other streams, when the 1987 generation estimates are compared with the 1991 estimates, the difference is statistically significant. For some streams, the quantity has decreased over time, while others have increased. When comparisons are made between two consecutive years, the differences are more subtle. Thus, observation of statistically significant differences between years must be critically reviewed and interpreted to determine if the difference is truly meaningful.

In some cases, the changes are fairly easy to interpret:

- for **API Separator Sludge** and **DAF Float,** listed hazardous wastes, the 1991 quantity is substantially *less* than that generated in 1987 and reflects the conscientious effort by the industry to reduce the amount of these materials generated;

- for **Pond sediments**, a *peak* in generation occurred in 1990 as more refiners closed surface impoundments, prior to the effective dates for the TC and primary sludge regulatory initiatives;

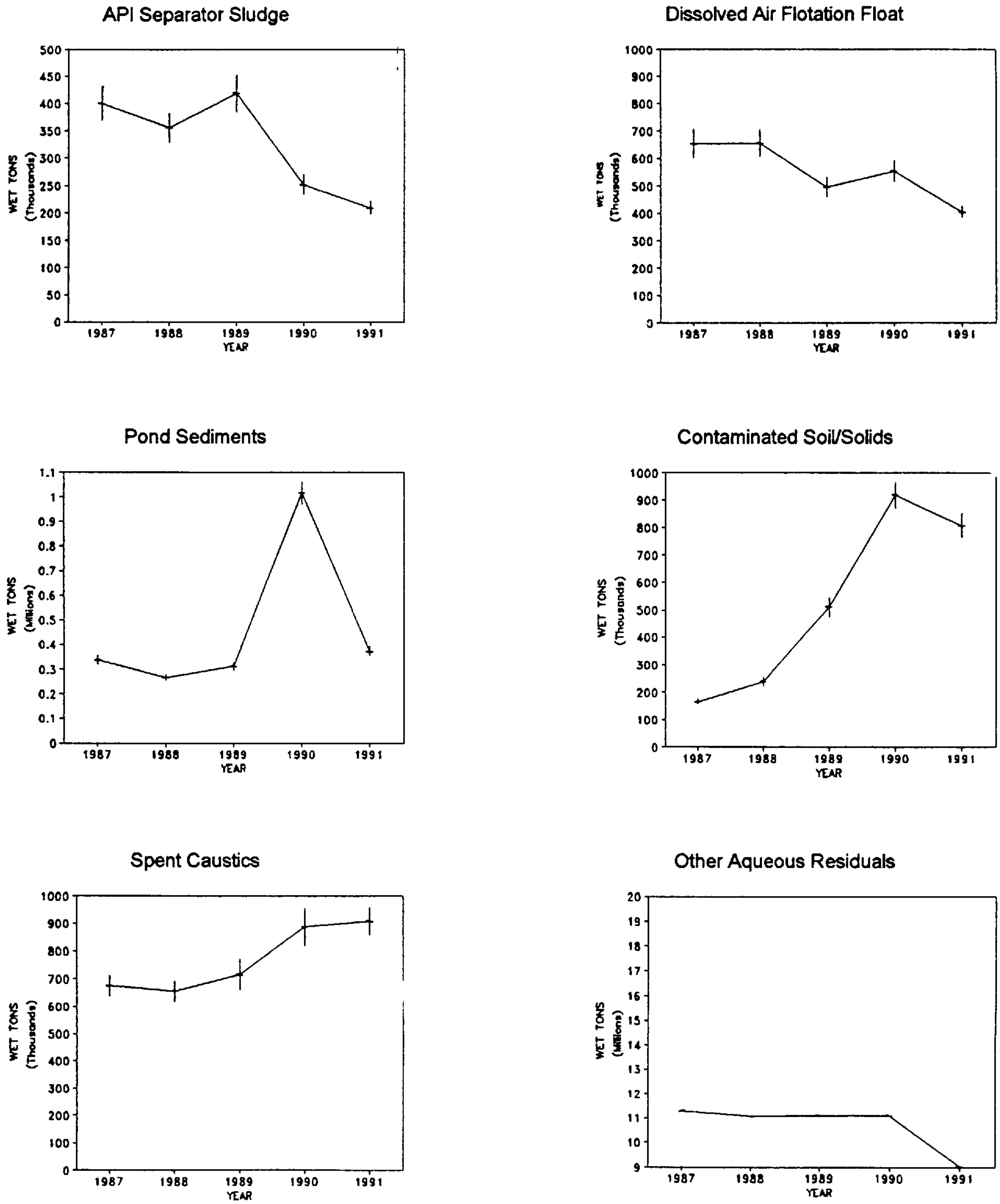
- for **Contaminated soils,** the quantity generated *increased* significantly each year from 1987 to 1990 as more refineries initiated construction projects and remediated sites;

- for **spent caustics** there have been successive *increases* in the generation quantities that appear to reflect differences in the reporting of these materials (i.e., as more emphasis has been placed on beneficial reuse of residual materials, refiners have increased reporting spent caustics as a residual material, whereas previously this material had not been considered a residual because it was resold for subsequent use);

- for **Other aqueous residuals**, the generation quantity *dropped* in 1991 as some refiners phased out reliance on injection wells for these dilute materials.

Trend graphs for these streams are presented on the following page.

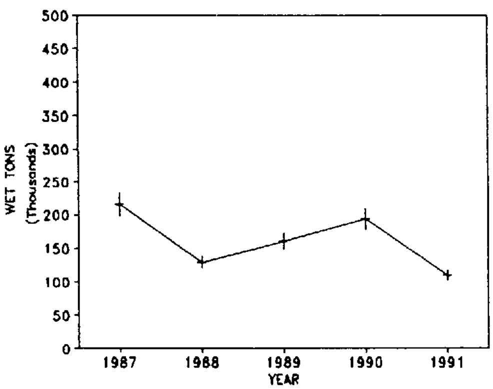
Figure K
Residual Generation Curves for Streams with Significant Trends



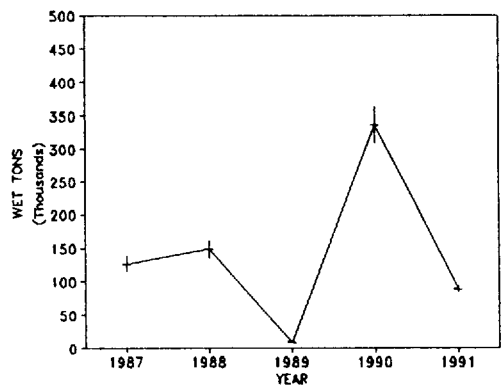
It appears that there is another grouping of streams--those for which there is no discernable pattern in generation, and for which there is no ready explanation of the variability. Note the graphs for **Nonleaded tank bottoms** and **Spent acids** in which the quantities generated each year fluctuate, as do the variances of each respective estimate.

Figure L
Residual Generation Curves for Streams with Unexplained Variability

Nonleaded Tank Bottoms



Spent Acids



The graphs for several other streams, **biomass, residual oils/spent solvents, residual coke/carbon/charcoal** also show substantial fluctuations between years that are statistically significant. For these streams, it appears that the variability can be attributed to fluctuations in the quantities reported by several, but not all refineries. Although it is unclear why the quantities reported by individual refineries varied so greatly, this pattern of reporting signaled the need for further analysis to more clearly understand these variations. Consequently, API performed a covariance analysis on the cohort of 70 refineries that had participated in all five survey years.

This covariance analysis was similar to that performed with the first three survey cycles of data in the 1989 report. Streams with five year industry-wide means of at least 100,000 wet tons were selected for study. Ten streams met this criteria. For the cohort of refineries, coefficients of variation (i.e., the standard deviation expressed as a percentage of the mean) were determined for both the industry-wide mean generation quantity for the 1987 - 1991 survey period and for each refinery reporting each waste stream. These data are arrayed in Table 5 in ascending order of the coefficient of variation for the industry; the median coefficient of variation for the individual refineries is presented in the next column.

Table 5
Covariance Data on Residual Generation Rates: 1987 - 1991 (Cohort of 70 refineries)

Residual Stream	Mean Residual Managed by Cohort 1987-1991	Coefficient of Variation for Cohort	Median Coefficient of Variation for Individual Refineries
Biomass	455,540	11	109
DAF Float	280,414	14	77
Spent Caustic	508,084	17	85
FCC Catalyst or Equivalent	105,776	19	51
Other Residuals NOS	220,029	28	98
Other Inorganic Residuals NOS	225,172	27	93
Slop Oil Emulsion Solids	126,840	32	134
API Separator Sludge	213,221	50	91
Pond Sediments	303,949	58	199
Contaminated Soils/Solids	329,275	67	122

The industry-wide coefficient of variation ranged from 11 to 67 percent. The median coefficient of variation for refineries is consistently higher, ranging from 51 to 199. Moreover, the refinery specific coefficients of variation are two to ten times larger than the industry-wide coefficients. For example, for **biomass**, the industry-wide coefficient of 11 percent is 10 times smaller than the individual refinery median variation of 109 percent. Moving to the bottom of the table, the individual refinery coefficient for **contaminated soils/solids** is 122, but since this stream also has the second largest industry coefficient, the individual coefficient is only two times larger.

It is difficult to posit many meaningful interpretations of these data. It comes as no surprise that **pond sediments** and **contaminated soils/solids** exhibit the greatest variability. Both of these streams had large, abnormal/one-time generation peaks in 1990, which clearly contribute to the variability. Similarly, it is reasonable that **FCCU catalyst or equivalent** is intermediate in the table, since this stream is generated continually and has not varied substantially over time.

Even though it is hard to interpret the variability for individual streams, this covariance analysis makes it clear that site-specific considerations are critical in residual generation patterns. This source of variability must be factored into interpretations of the data, and any subsequent applications or inferences drawn from the data.

POLLUTION PREVENTION

As described in the Methodology section, a pollution prevention item was included on each data sheet. Refiners were asked to report, for each stream, activities that reduced the quantity of residual generated and/or the amount that might eventually require disposal. With the expanded listing of activity categories--both source reduction methods and codes to report in-process and out-of-process recycling--the number of refineries that reported any pollution prevention activities was 61, one less than the 62 that reported initiating source reduction activities in 1990. Most refiners reported more than one pollution prevention activity. The total number of activities reported was 274, close to 70 more than reported in 1990.

Refiners attributed a substantial reduction in residuals to pollution prevention activities: a total of 751,319 wet tons.

When comparing this with 1990, the revision in the question for 1991 must be kept in mind. The most valid comparison is to contrast the 751 thousand wet tons reported as pollution prevention in 1991 with the 315,524 wet tons of material reported in 1990 as prevented due to source reduction activities *summed* with the 143,841 thousand wet tons that were reported as reused or recycled under the resource recovery data item in the 1990 questionnaire. Comparison of the 751 thousand for 1991 with the total of 460 thousand for 1990 yields a 63 percent increase in the quantity of residuals reported by survey participants that were reduced at the source, recycled or otherwise reused or reclaimed.

Table 6 presents the frequency counts for each pollution prevention method.

Table 6
Number Refineries Reporting Each Pollution Prevention Activity

Pollution Prevention Activity	# Citations
Equipment or Technology Modifications	24
Procedure Modifications	23
Reformulation or Design of Products	3
Substitution of Raw Materials	13
Improved Housekeeping, Training, or Inventory Control	43
IN-PROCESS RECYCLE	
In refining process units (e.g., crude unit; coker; desalter)	42
Recovering oil (& dewatering) by filter pressing/centrifugation	50
Other recycle	5
OUT-OF-PROCESS RECYCLE	
Reuse/reclamation	66
Other	10

The most frequently reported activity was *reuse/reclamation* of materials, an out-of-process recycle method. As documented previously, the industry relies extensively on these methods to manage catalysts and chemicals used in the refining process. *Improving oil recovery operations* was the second highest activity cited, as might be expected in a year when land disposal restrictions on oily materials provided incentives to minimize the amount of these materials requiring disposal. *Housekeeping, training, and inventory control improvements*--the low hanging fruit of pollution prevention which can be readily implemented without large capital expense--was next, followed by *in-process recycle* of oily materials.

Procedure modifications and *equipment and technology modifications* received 23 and 24 responses, respectively. This was a substantial drop in the number of procedure modifications which was cited 73 times in 1990. Mentions of equipment and technology modifications were comparable with 18 in 1990 and 24 this year. Reporting *substitution of raw materials* doubled over the year, and although it remained a low frequency response--just 13--its increase attests to some of the toxics use reductions implemented by the industry: replacing chromates in cooling towers; using water-based solvents for cleaning operations; replacing asbestos insulation; and substituting other oils for PCBs in electrical equipment.

The fluctuations in these frequency counts serve as reminders of anticipated trends in pollution prevention and source reduction activities. Recycling of oily materials and spent chemicals/caustics is an ongoing activity that is reported each year. Hence the repeated, high frequency counts. As suggested above, some activities, typically the housekeeping improvements, can be implemented without much capital expense. Some of these improvements may be reported only once, like the paving of process areas to reduce dust and solids entering the sewer system, while others, like sweeping, may be ongoing and are reported successively.

Procedure modifications usually optimize operations, and are dependent on formalized analysis of current procedures. These innovations and any related reductions in residuals are reported for the year they were initiated. Although these modifications become part of ongoing operating procedures, they may only be counted the year they came online. Equipment and technology modifications, like efforts to reformulate products or substitute raw materials, generally require research and monetary investments to develop and implement. Because they take longer to achieve, frequency counts for these activities are expected to remain low.

The summary statistics in Table 6 provide an overview of the industry's continuing efforts to improve its operating practices. Looking at this same pollution prevention data, but arrayed by residual stream, reinforces the view that the industry dedicates substantial effort to optimizing management practices. As Table 7 reveals, refiners reported some pollution prevention activity for 26 of the 29 residual streams. Moreover, for 24 streams, there were two or more different pollution prevention activities performed.

Table 7
Summary of Pollution Prevention Activities

			SOURCE REDUCTION					RECYCLE IN-PROCESS			RECYCLE OUT-OF-PROCESS	
Residual stream	# Refineries	Wet Tons	1	2	3	4	5	6	7	8	9	10
API Separator Sludge	36	103,291	✓	✓			✓	✓	✓		✓	
DAF Float	20	195,411	✓	✓			✓	✓	✓	✓	✓	
Slop Oil Emulsion Solids	16	20,489	✓				✓	✓	✓		✓	
Leaded Tank Bottoms	5	41			✓				✓			
Pond Sediments	4	6,348		✓				✓				
Nonleaded Tank Bottoms	9	22,257						✓	✓		✓	
Residual Oils/Spent Solvents	8	373	✓			✓	✓	✓		✓	✓	
Other Oily Sludges/Organic Wastes	4	148	✓				✓	✓	✓			
Primary Sludge (F037)	10	38,602	✓	✓			✓	✓	✓			
Primary Sludge (F038)	4	495						✓			✓	
Heat Exch Bundle Cleaning Sludge	5	179						✓	✓			
Contaminated Soil/Solids	12	16,470	✓	✓			✓				✓	
Residual coke/Carbon/Charcoal	4	311					✓				✓	
Residual sulfur	2	223	✓				✓					
Other contaminated soils	7	470		✓			✓				✓	

POLLUTION PREVENTION CODES
1 = Equipment or Technology Modifications
2 = Procedure Modifications
3 = Reformulation or Design of Products
4 = Substitution of Raw Materials
5 = Improved Housekeeping, Training, or Inventory Control

IN-PROCESS RECYCLE
6 = In refining process units (e.g., crude unit; coker; desalter)
7 = Recovering oil (& dewatering) by filter pressing/centrifugation
8 = Other recycle

OUT-OF-PROCESS RECYCLE
9 = Reuse/reclamation
10 = Other

Table 7 (contd)

Summary of Pollution Prevention Activities

			SOURCE REDUCTION					RECYCLE IN-PROCESS			RECYCLE OUT-OF-PROCESS	
Residual stream	**# Refineries**	**Wet Tons**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
FCC Catalyst or Equivalent	14	16,159	✓					✓			✓	
Hydroprocessing catalysts	7	6,214						✓			✓	
Other Spent Catalysts	8	1,215	✓	✓							✓	
Biomass	8	212,595	✓	✓			✓	✓	✓	✓		
Oil contaminated water (not WW)	1	431	✓									
High pH/low pH waters	2	10,548		✓								✓
Other aqueous wastes NOS	1	113									✓	
Spent caustics	12	63,954	✓	✓				✓			✓	
Residual amines	4	15,853					✓				✓	
Other inorganic residuals NOS	4	6,515						✓	✓		✓	
Other residuals NOS	10	12,614		✓		✓	✓	✓			✓	✓
TOTAL	274	751,319										

POLLUTION PREVENTION CODES
1 = Equipment or Technology Modifications
2 = Procedure Modifications
3 = Reformulation or Design of Products
4 = Substitution of Raw Materials
5 = Improved Housekeeping, Training, or Inventory Control

IN-PROCESS RECYCLE
6 = In refining process units (e.g., crude unit; coker; desalter)
7 = Recovering oil (& dewatering) by filter pressing/centrifugation
8 = Other recycle

OUT-OF-PROCESS RECYCLE
9 = Reuse/reclamation
10 = Other

The greatest reduction, 213 thousand wet tons, was reported for biomass. The eight refiners with biomass reductions implemented a variety of pollution prevention activities:

- improving equipment by installing a steam dryer;
- optimizing procedures by using chemicals for dewatering and stopping use of an impoundment;
- improving housekeeping to avoid contamination of the wastewater system;
- recycling biomass by injecting it into the crude conversion unit, by improving deoiling or by using it to re-seed the refinery's land biotreatment unit.

DAF float had the second greatest reduction, followed by **API separator sludge** (195 and 103 thousand wet tons, respectively). When these RCRA listed hazardous wastes are combined with the other regulated streams (**Slop oil emulsion solids, leaded tank bottoms, heat exchanger bundle cleaning sludge** and the **primary sludges**), they total 359 thousand wet tons or 48 percent of the total quantity that was prevented.

As the check marks in Table 7 indicate, refineries used a variety of pollution prevention activities with these five streams. As might be expected for these oily materials, in-process recycling to either process units (e.g., crude units or cokers) or via improved deoiling/ dewatering, were cited for all these streams. Technology/equipment improvements included installing thermal dryers to maximize deoiling/dewatering, segregating the sewer system, installing new feed equipment to the filter press, or installing zero sample valves at all units. Procedure improvements ranged from use of safe-t-caps during hot work, to segregating residuals (particularly biosludge), to optimizing decanting. The housekeeping improvements focused on suppressing dust and soil from entering the sewers, either by paving, regrading or sweeping process and tank areas, or by "dry" cleaning process areas. More information on the pollution prevention methods reported for each stream can be found in Appendix C.

The other residual stream for which refiners reported a substantial pollution prevention quantity was **spent caustics** (64 thousand wet tons). Recycling, particularly out-of-process reuse by paper and chemical manufacturers, or on-site at bio-ponds for pH control, accounted for much of the spent caustics. As shown in Appendix C, in-process recycle methods involved use of prewash caustics by other treaters or "captive" use within a company, but at another refinery.

The amount of material attributed to pollution prevention activity was much smaller for the remaining residual streams. Refiners reported the in-process recycle of 22 thousand tons of **nonleaded tank bottoms. FCCU catalyst or equivalent** and **contaminated soils/solids** both had 16 thousand wet tons reported, by 14 and 12 refineries, respectively. The pollution prevention activities for **FCCU catalyst or equivalent**, a residual generated on a continuous basis, represented 8 percent of the total amount of this stream generated. The reductions reflect engineering changes in the cyclones, as well as out-of-process regeneration or recycling of the residual to steel and cement manufacturers.

In contrast, the amount of **contaminated soil/solids** prevented represented barely 2 percent of the total amount generated. As would be anticipated for a stream that is not methodically generated (i.e, contaminated soils result from abnormal, one time events such as spills or from infrequent, periodic initiatives such as construction of new units or remediation of a site), housekeeping improvements were cited to avoid future contamination. In addition, some of this contaminated material was recycled via cement kilns. An interesting procedure modification reported was the use of recyclable steel grit with a containment system which reduced the amount of sand blast grit generated (and disposed).

For more information on the pollution prevention activities conducted on other residual streams, readers should refer to the respective tables in Appendix C.

TOTAL QUANTITY OF RESIDUALS MANAGED

API has used *total quantity managed* to refer to the total amount of residual materials which refineries must handle in a given calendar year. This phrase makes an explicit reference to the waste management hierarchy, wherein residual materials are eliminated from further handling by a combination of recycling, treatment, and/or disposal[3]. The quantity managed is usually larger than the quantity generated, because refiners add treatment materials to facilitate subsequent handling of some residuals, while additional material that had been in storage can be removed for final disposition. The following equation shows the various components.

Total Quantity Managed = Quantity Generated + Treatment Additives + Net From Storage

As described earlier, a total of 5,809 thousand wet tons of residuals were *generated* in 1991. After accounting for the use of treatment additives and movement of materials in and out of storage, it was estimated that the industry *managed* a total of 5,808 thousand wet tons of residual material. This difference of only 1 thousand tons was the smallest ever observed between these two measures. In the past, treatment additives plus the removal of residuals from storage have created a larger increase in the 100 thousand wet tons range.

Table 8 presents a listing, by stream, of the wet tons generated plus treatment additives and the net from storage. As the summary row at the bottom of the table indicates, the amount of treatment additives used was offset by residuals placed into storage in 1991. The 42 thousand wet tons placed into storage included 24 thousand of **contaminated soils/solids**, eight thousand of **slop oil emulsion solids**, six thousand of **DAF float**, and 4 thousand of **inorganic residuals NOS**.

The use of treatment additives has fluctuated over the five years, reaching a high of 88 thousand wet tons in 1990, when the peak in generation of pond sediments necessitated use of more additives. One year earlier, in 1989, the low of 35 thousand wet tons was reported. The 42 thousand for 1991 is the second lowest ever reported, and represents reductions in the use of additives for **spent caustics,** and, as would be expected when regulatory constraints emphasized minimizing the quantity of listed hazardous wastes, **DAF float, API separator sludge** and **slop oil emulsion solids.**

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[3] As described previously, **Other Aqueous Residuals NOS** are typically deep well injected without any prior effort to minimize the quantity by recycling or treatment. Because of this, this stream was handled separately in 1991 and is not included in the total quantity of residuals discussed in this section.

Table 8
Estimates of Residual Materials Managed in 1991 (thousand wet tons)

Residual streams	Amount Generated	Treatment Additives	Net From Storage	Total Amount Managed
Spent caustics	909		(1)	908
Biomass	855	7	<1	862
Contaminated soils/solids	809	<1	(24)	785
DAF float	406	9	(6)	410
Inorganic residuals NOS	397	<1	(4)	393
Pond sediments	372	8	0	381
Other residuals NOS	339	0	<1	339
API separator sludge	210	5	(1)	214
FCC catalyst/equivalent	204	0	0	204
Other separator sludges				
Primary Sludge (F038)	177	3	(<1)	180
Primary Sludge (F037)	130	2	<1	133
TSD Leachate (F039)	20	0	0	20
Slop oil emulsion solids	165	3	(8)	160
Residual coke/carbon/charcoal	138	0	(<1)	138
Residual amines	136	0	<1	137
Nonleaded tank bottoms	109	2	(<1)	111
Spent acids	88	<1	0	88
Oil contaminated waters (not wastewaters)	67	0	0	67
High pH/low pH waters	54	0	0	54
Oily sludges/organic residuals NOS	54	<1	(<1)	54
Contaminated soils NOS	37	<1	(<1)	37
Hydroprocessing catalysts	32	0	<1	33
Spent Stretford solution	25	0	(<1)	25
Other spent catalysts	23	<1	<1	23
Residual oils/spent solvents	21	0	(<1)	21
Residual sulfur	19	0	<1	19
Spent sulfite solution	9	0	<1	9
Heat exch bundle cleaning sludge	3	<1	(<1)	3
Leaded tank bottoms	1	0	(<1)	1
Total	5,809	42	(43)	5,808

Table 9 compares the total quantity of residuals managed in 1991 with the data for the preceding four years. As shown, 1991 weighed in with the second largest quantity of residuals to manage, substantially lower than the high of 1990, and generally comparable to the quantities reported prior to that peak. Given that the influence of treatment additives and storage activity was negligible, the patterns observed in generation rates remained valid: the largest increase was noted for **biomass** and the quantity of **primary sludge** increased. Sizeable reductions were recorded for **pond sediments**, the **listed hazardous wastes**, and **contaminated soils/solids**.

Table 9
Comparison of Residual Material Managed: 1991-1987
(Estimates in thousands of wet tons)

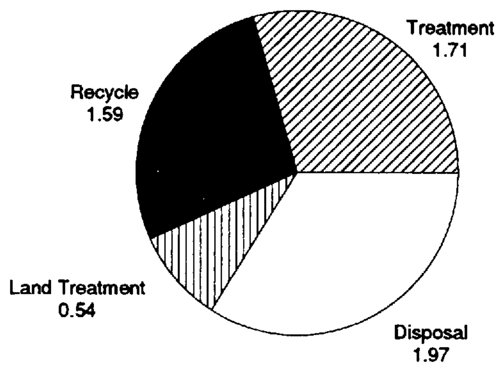
Residual streams	1991	1990	1989	1988	1987
Spent caustics	908	894	716	656	675
Biomass	862	794	655	749	720
Contaminated soils/solids	785	915	496	242	186
DAF float	410	564	521	661	654
Inorganic residuals NOS	393	453	441	221	323
Pond sediments	381	1,040	273	311	360
Other residuals NOS	339	353	325	412	203
API separator sludge	214	260	425	430	564
FCC catalyst/equivalent	204	259	185	189	171
Other separator sludges	NA	104	117	110	83
Primary Sludge (F038)	180	NA	NA	NA	NA
Primary Sludge (F037)	133	NA	NA	NA	NA
TSD Leachate (F039)	20	NA	NA	NA	NA
Slop oil emulsion solids	160	295	262	214	212
Residual coke/carbon/charcoal	138	92	137	67	43
Residual amines	137	75	51	14	13
Nonleaded tank bottoms	111	196	164	131	218
Spent acids	88	337	8	160	130
Oil contaminated waters (not wastewaters)	67	8	29	36	28
High pH/low pH waters	54	105	92	138	144
Oily sludges/organic residuals NOS	54	54	47	61	40
Contaminated soils NOS	37	69	53	77	88
Hydroprocessing catalysts	33	30	36	37	39
Spent Stretford solution	25	30	42	49	35
Other spent catalysts	23	41	33	38	38
Residual oils/spent solvents	21	115	31	7	4
Residual sulfur	19	35	52	23	17
Spent sulfite solution	9	1	8	40	42
Heat exch bundle cleaning sludge	3	13	2	5	3
Leaded tank bottoms	1	3	4	10	9
Total	5,808	7,134	5,206	5,086	5,043

MANAGEMENT PRACTICES FOR RESIDUAL MATERIALS

As described in the Methodology section, the data sheets require respondents to categorize the disposition of each waste stream according to the waste management hierarchy of recycle, treatment and disposal. (Even though it was collected under the broader category of treatment, API breaks out land treatment data and reports it separately.)

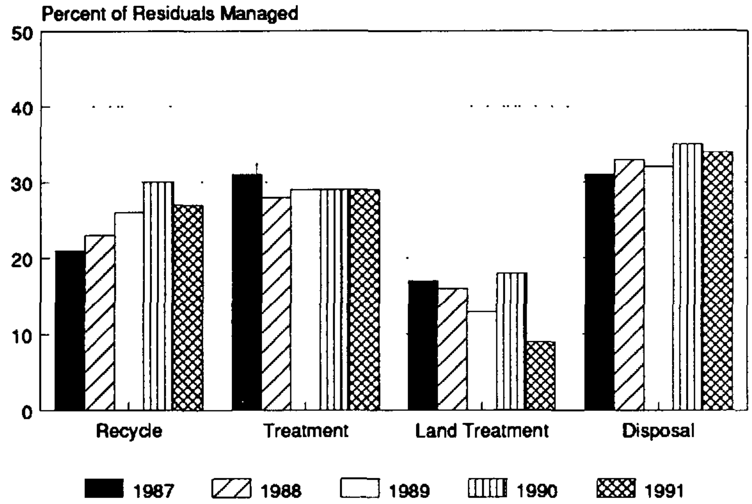
Figure M illustrates how the industry manages its residuals. As the filled portions of the pie chart show, approximately two thirds are either recycled, treated or land treated, while one third is disposed.

Figure M
Summary of Residual Management Practices for 1991 (millions of wet tons)



As shown in Figure N, this distribution of handling practices is similar to that reported in previous years.

Figure N
Longitudinal Comparison of Residual Management Practices: 1987-1991



The amount of residuals recycled has increased since the survey began, while the use of treatment has remained fairly constant.[4] Use of land treatment has diminished over the last five years, although 1990 witnessed an increase due to the industry's use of this modality to handle the peak quantities of pond sediments and contaminated soils generated from construction and site remediation activities undertaken in 1990. Disposal needs have remained constant, particularly when one considers that refiners had to resort to disposal technology to handle the large quantities of contaminated soils generated during the last two survey cycles.

The following sections of the report describe how recycling, treatment, land treatment and disposal were used by the industry. The data on the amount of each stream handled by the various management methods provide an interesting picture of how the industry handles its wastes, and alludes to the multiplicity of factors that affect how a residual will be handled. The SAS print-outs that support the following analysis are presented in Appendix D.

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[4]This graphic presentation is based on the estimation procedures used for the 1991 data, wherein: 1) a separate model was used for Other Aqueous Residuals and 2) observations determined to be statistical outliers were included in the calculations that apportion the total quantity of residual managed across the various handling procedures. This has resulted in a change in the data for 1990 which had previously been presented without the influence of the Other Aqueous Wastes and any other statistical outliers. Specifically, the graphic protrayal of the data in the 1990 report showed decreases in treatment and land treatment which several of the outliers used to handle the peak quantities of pond sediments and contaminated soils.

Recycling

The general pattern of recycling residuals has remained constant over the five year survey period. As shown in Table 10, **reclamation/regeneration** continues to account for almost one half of the material recycled. When summed, in-process recycling, either to the **coker**, the **crude unit**, or to the new category used in the 1991 questionnaire that includes desalter, catalytic cracker and other, represents 29 percent. The other new categories, **out-of-process** that includes non-fuel reuse, such as cement kiln feed, were used with 5 percent of the residuals. Similarly, use as **industrial fuels**, also accounted for 5 percent.

Table 10
Summary of Recycling Practices
(thousands of wet tons)

Method of Recycling	1991 Tons	%	1990 Tons	%	1989 Tons	%	1988 Tons	%	1987 Tons	%
Coker	181	11	192	10	231	17	186	16	148	14
Crude unit	217	14	174	9	125	9	85	7	68	6
Reclamation/regeneration	772	49	872	46	611	44	434	38	447	42
Other recycling			655	35	408	30	474	41	410	38
In-process*	60	4								
Out-of-process*	84	5								
Fuel use*	78	5								
Not specified*	198	12								
Total	1590	100	1,893	100	1,376	100	1,179	100	1,073	100

*These categories were new for 1991; data were not available for previous years.

Table 11 shows the contributions made by stream, to the total quantity of residual managed by each recycling method. As in previous years, **spent caustics** accounts for over half of the residual that is *reclaimed or regenerated.* From the pollution prevention data, it is known that much of this was sold to paper mills and chemical manufacturers. An increase in the quantity of **residual coke/carbon/charcoal** regenerated was reported and reflects the new pollution prevention practice reported whereby carbon was sent off-site for regeneration. Note that the amount of spent acids that is regenerated or reclaimed has varied substantially over the survey period, while the amount of **hydroprocessing catalysts** has remained constant.

Looking at the residuals that are sent to the coker for recycling, it appears that refiners are using this method to handle more **biomass**. The coker is also used for residuals that if disposed, would be listed hazardous wastes, namely **API separator sludge, DAF float** and **slop oil emulsion solids**. The quantities handled each year vary substantially.

In 1991, refiners sent 79 thousand wet tons of **biomass** to the crude unit; in previous years the quantity had been negligible. The amount of **DAF float** going to the crude unit was the highest ever reported. The variability noted with **residual oils/spent solvents** may reflect reporting by different refineries in each year that employ various methods of handling these materials.

Overall, the out-of-process recycle categories used in 1991 accounted for 162 thousand wet tons or approximately 10 percent of the materials recycled. Thirty three thousand wet tons or 65 percent of the out-of-process recycle to cement kilns was **FCCU catalyst**; 7 percent was **API separator sludge**. Listed residual material accounted for 86 percent of the 51 thousand wet tons recycled out-of-process as fuel for cement kilns.

The amount of residuals handled by "Other" methods represented 12 percent of the total (198 thousand wet tons), most of which was **spent caustics.**

Table 11
Estimated Quantities of Recycled Materials (thousands of wet tons)

Recycling Method/Residual Stream	1991	1990	1989	1988	1987
RECLAMATION/REGENERATION					
Spent caustics	486	535	459	243	262
Residual coke/carbon/charcoal	100	48	40	43	27
Spent acids	80	200	0	56	57
Hydroprocessing catalysts	31	28	32	21	26
Other Residuals NOS	45				
All others	30	54	35	120	212
Total	772	872	611	378	390
IN-PROCESS RECYCLE-Coker					
Biomass	67	56	59	27	25
DAF float	56	75	79	45	82
API separator sludge	31	8	55	73	14
Slop oil emulsion solids	18	42	9	23	19
All others	9	4	6	11	8
Total	181	192	231	186	148
Crude unit					
Biomass	79				
DAF float	72	22	34	19	16
Residual Oils/Spent Solvents	15	64	0	0	0
Nonleaded tank bottoms	15	34	18	13	11
Slop oil emulsion solids	14	29	17	27	12
API separator sludge	11	10	24	13	18
All others	11	2	6	0	3
Total	217	174	125	85	68
Other In-Process Recycle	60	These recycle codes were new for 1991; consequently comparable data were not available for previous survey cycles			
Out-of-Process Kiln	51				
Other Out-of-process	33				
Industrial Fuel	78				
Other*					
Spent caustics	137	123	138	254	232
Contaminated soil	20				
Other inorganic residuals NOS	13	102	6	14	18
Other residuals NOS	13				
All others	15	218	141	220	178
Total	198	655	409	474	410
Grand total	1,590	1,893	1,369	1,156	1,055

Table 12 shows where recycling was performed. As expected, oily residuals and biomass that are recycled in-process are handled primarily on-site, while spent chemical and catalysts that are regenerated or reclaimed are handled off-site. The most evenly divided stream was **Spent caustics**, reflecting the on-site reuse of the material to adjust pH in biotreatment units, and off-site as feed for paper mills and in steel manufacturing. Also, note that one quarter of **slop oil emulsion solids** and one-third of **API separator sludge** were recycled off-site, principally as industrial fuels.

Table 12
Location of Recycling Activities
(thousands of wet tons)

Residual Stream	Quantity	% On-Site	% Off-site
Spent caustics	646	47	53
Biomass	147	100	0
DAF float	140	92	8
Residual coke/carbon/charcoal	121	3	97
Spent acids	84	0	100
Slop oil emulsion solids	81	75	25
Other residuals NOS	63	1	99
API separator sludge	62	67	33
FCC catalyst or equivalent	56	4	96
Other Inorganic Residuals NOS	46	3	97

Treatment

A five-year profile of treatment practices is presented in Table 13. Use of wastewater treatment increased in 1991, as did industry's use of incineration. Reliance on chemical and physical treatment methods dropped over the life of the survey. Stabilization/fixation returned to the low level observed before the peak in 1990 when closure of surface impoundments created large quantities of pond sediments.

Table 13
Summary of Treatment Methods
(thousands of wet tons)

Method of Treatment	1991 Tons	%	1990 Tons	%	1989 Tons	%	1988 Tons	%	1987 Tons	%
Wastewater	1464	86	1,265	68	1,176	78	1,045	72	1,167	74
Incineration	215	13	165	9	143	9	131	9	107	7
Chemical/physical	3	<1	131	7	143	9	148	10	117	7
Stabilize/Fixation	3	<1	276	15	4	<1	5	<1	<1	<1
Other	22	1	37	2	45	3	117	8	186	12
Total	1,707	100	1,874	100	1,511	100	1,446	100	1,577	100

As with recycling, the data on how individual streams are treated seem to counter the impression of status quo created by the summary statistics presented above. From Table 14 it is clear that the increase in reliance on wastewater treatment reflects changes in handling practices. The amount of *dewatered oily materials* was intermediate when compared with previous years, while the amount of *aqueous chemical wastes/inorganics* was higher than ever reported before.

Looking further, there are noteworthy changes within each of these wastewater treatment methods. For *dewatered oily materials*, the amount of **DAF float** was the lowest ever; the quantities of **API separator sludge** and **slop oil emulsion solids** were also below the average expected from the observations in the previous four years. These decreases are offset, however, by the use of this treatment for the newly listed **primary sludges** (F037 and F038). This pattern suggests that while source reduction activities have diminished the amount of some oily materials, these advances are overshadowed by the impact of other regulatory initiatives.

Wastewater treatment of *aqueous chemical wastes/organics* increased, but the relative contributions made by the respective streams remained fairly constant. **Biomass** continued to be the largest stream, followed by **spent caustics, residual amines,** and **other inorganic residuals.**

As noted, use of incineration continued to increase, yet still represented less than 15 percent of the residuals treated. A reflection of BDAT requirements, incineration was used to eliminate more **DAF float, API separator sludge** and **slop oil emulsion solids** in 1991. The amount of **biomass** incinerated dropped, while more **pond sediments** were sent for incineration.

Table 14
Estimated Quantities of Residuals Treated (thousands of wet tons)

Treatment Method/Residual stream	1991	1990	1989	1988	1987
Wastewater treatment					
From dewatered oily materials					
DAF Float	208	306	248	236	263
Primary Sludges (F037 & F038)*	197	51	53	48	32
API separator sludge	113	56	149	136	146
Slop oil emulsion solids	58	108	98	57	98
Others (Pond Sediments or Nonleaded Tank Bottoms)	0	38	85	52	161
Subtotal	576	559	633	529	700
Aqueous chemical wastes/inorganics					
Biomass	354	288	249	222	234
Spent caustics	229	132	93	74	87
Residual amines	133	71	46	2	2
Other inorganic residuals NOS	70	50	23	39	33
Oil contaminated waters (not wastewaters)	59	1	19	35	26
Spent Stretford solution	18	16	29	39	17
All others	25	58	31	594	735
Total	1464	1,265	1,176	1,045	1,167
Incineration					
Biomass	82	98	103	73	64
DAF float	58	32	26	47	35
API separator sludge	29	5	7	5	4
Pond Sediments	19	0	0	0	0
Slop oil emulsion solids	19	<1	<1	4	1
All others	8	3	6	2	3
Total	215	164	143	131	107
Chemical/physical					
API separator sludge	2	13	35	10	2
Biomass	0	20	0	17	0
All others	<1	98	25	120	98
Total	3	131	143	131	117
Stabilize/Fixation	3	276	4	0	<1
Weathering/Other					
Biomass	13	0	0	0	0
Others	9	36	49	122	186
Total	22	36	49	122	186
Grand total	1,707	1,877	1,511	1,446	1,577

*Quantities reported for 1987 - 1990 were for Other Separator Sludges

Chemical/physical and stabilization/fixation treatments accounted for less than 1 percent of the materials treated. Refiners used chemical/physical methods to handle ash from the incineration of **API separator sludge** and used stabilization techniques to manage **pond sediments.**

The remaining methodology category captured weathering treatment of **biomass** and the thermal treatment of **API separator sludge** and **DAF float** (the 9 thousand wet tons listed as "Other").

As shown in Table 15, the vast majority of residuals are treated on-site. Off-site treatment primarily reflects use of commercial incinerators for **biomass** and **pond sediments.** Almost half of the **other inorganics NOS** were sent off-site for wastewater treatment, probably due to circumstances where these aqueous inorganics were incompatible with the on-site wastewater treatment system and had to be handled by outside commercial vendors.

Table 15
Location of Treatment Activities
(thousands of wet tons)

Residuals Stream	Quantity	% On-Site	% Off-site
Biomass	449	61	39
DAF float	267	92	8
Spent caustics	229	82	18
API separator sludge	147	81	19
Primary sludge (F038)	139	100	0
Residual amines	134	100	0
Other inorganic residuals	70	52	48
Slop oil emulsion solids	78	75	25
Oil contaminated water (not WW)	59	100	0
Primary sludge (F037)	59	98	2
Pond sediments	29	35	65

The frequency of refineries reporting wastewater treatment and incineration provide a final interesting detail: the 86 percent of residuals treated in wastewater systems reflects 193 citations, while the 13 percent incinerated result from 223 reports. Thus, it is clear that refiners send quite small quantities of a variety of materials to incinerators, while large quantities of a more limited set of streams are handled via wastewater treatment.

Land Treatment

When refiners complete the data sheets, land treatment appears as a methodology option for eliminating or minimizing residuals through treatment. It is land-based "bio-remediation" technology wherein living organisms metabolize, and thus degrade, organic materials.[5] Despite its efficacy, the practice was subject to the RCRA land disposal restriction for the handling of hazardous wastes because the residuals are placed on the land. Thus, beginning in 1990, listed hazardous wastes which were subject to land disposal restrictions, could no longer be land treated unless the land treatment unit successfully completed a "no migration" petition.

[5] In land treatment, organic wastes and residual materials are tilled with fertilizers into soil, and watered. Tilling oxygenates the mixture, while the nutrients and moisture encourage the growth of biological organisms that feed on organics.

Because of these restrictions, a drop in the use of land treatment was expected for 1991. Although this did occur, the decrement was smaller than anticipated. As the data in Table 16 show, the big drop in land treatment for listed hazardous wastes occurred between 1988 and 1989. This decrease was countered by an increased use of land treatment for the growing quantities of **contaminated soils/solids** and **pond sediments**, and the readily available quantities of **biomass** for moisture. Again, the summary statistic belies the fluctuations that occur among the various streams.

Table 16
Estimated Quantities of Land Treated Residuals (thousands of wet tons)

Residual stream	1991	1990	1989	1988	1987
Contaminated soils/solids	268	299	132	28	22
Biomass	201	267	187	259	236
Primary sludge (F037)	27	NA	NA	NA	NA
Pond sediments	11	349	127	64	67
Nonleaded tank bottoms	9	23	36	34	58
Other oily sludges/organic residuals	9	5	6	6	11
Other inorganic residuals NOS	8	10	16	30	25
DAF float	<1	60	72	203	159
Other contaminated soils	2	7	10	28	22
API separator sludge	0	65	61	85	211
Slop oil emulsion solids	0	18	27	57	35
Other separator sludges	NA	31	30	22	12
All others	3	14	5	11	14
Total	538	1,148	709	832	850

The frequency counts--the highest was 12--suggested that possibly the 13 percent of material that was land treated represents a practice that only a few refineries conducted. Analysis of the response, however, revealed that over 30 refineries practiced land treatment. Reliance on this treatment varied across the refineries with four reporting use with only one stream (not necessarily the same stream), while there were other refineries that used land treatment with 9, 10, 11 or 12 different streams. It appears that the fluctuations in streams undergoing land treatment is not a simple trade-off among residual streams within a facility that has an operating land farm, but a more complex and dynamic phenomenon that involves the type of residual, its regulatory status and the facility's resources.

<u>Disposal</u>
Although it is the least favored option in the waste management hierarchy, disposal is a necessary component of every facility's residual management plan. After all efforts to reduce the generation of residuals, and to recycle and treat those that have been created, some material will inevitably remain which must be discarded.

In 1991, the refining industry disposed 1.97 million wet tons of residuals--34 percent of the total quantity generated. Recalling Figure M, the industry has disposed one third of the *residuals* generated in each survey year, although the actual amount disposed, as shown in Table 17, has fluctuated.

Table 17
Summary of Disposal Practices
(thousands of wet tons)

Method of Disposal	1991 Tons	%	1990 Tons	%	1989 Tons	%	1988 Tons	%	1987 Tons	%
Disposal impoundments	110	6	129	6	113	7	245	15	280	18
Landfills	1703	84	1,889	84	1,375	85	1,200	73	1,070	69
Landspread	66	3	174	8	95	6	160	10	109	7
Injection	35	2	36	2	15	1	30	2	40	3
Other	60	3	8	<1	21	1	1	<1	41	3
Total	1974	100	2236	100	1619	100	1636	100	1540	100

Disposal impoundments and landfills were used to dispose of 6 and 84 percent of residuals, respectively. This has remained constant over the last three years. The proportion of material landspread in 1991 was the lowest ever, while the use of deep wells to inject wastes continued to represent only 2 percent of material disposed.

The pattern of use of the various disposal methods also remained fairly static. As shown in Table 18, refiners used the most landfill capacity to handle **contaminated soils/solids, pond sediments, other residuals NOS**, and **other inorganic residuals NOS**. The quantity of **nonleaded tank bottoms** disposed in 1991 was comparable to that observed in 1990. Use of this modality with the listed hazardous wastes--**API separator sludge, DAF float** and **slop oil emulsion solids**--dropped substantially since only ash from incineration of these materials were landfilled.

Most other entries in the table were similar to 1990:

- refiners used *disposal impoundments* to handle **other inorganic residuals NOS** and **FCCU catalysts**;
- **biomass, other oily residuals, contaminated soils** and **pond sediments** were *landspread*;
- **spent caustics** were eliminated by *injection*; and
- **high pH/low pH waters** accounted for the most of the "Other" disposal.

The frequency counts of the number of refiners using each disposal method show that the only widespread disposal method used by the industry is landfilling. This ranged from highs of 105 refineries that reported using landfills to dispose **other residuals** and 91 refineries that cited it for **contaminated soils/solids**. In contrast, the frequency counts for each of the other disposal techniques were low, indicating that reliance on these methods was based on site-specific considerations regarding the type of residual and available disposal capacity.

Table 18
Estimated Quantities of Wastes Eliminated by Disposal (thousands of wet tons)

Disposal Method/Residual stream	1991	1990	1989	1988	1987
Disposal impoundment					
Other inorganic residuals NOS	53	86	65	25	56
FCC catalyst or equivalent	25	20	14	13	11
TSD Leachate (F039)	18	NA	NA	NA	NA
High ph/low Ph waters	0	13	24	16	25
All others	14	10	10	191	188
Total	110	129	113	245	280
Landfill					
Contaminated soils/solids	480	497	317	189	141
Pond sediments	328	405	60	50	7
Other residuals NOS	272	336	315	384	195
Other inorganic residuals NOS	210	162	227	77	155
FCC catalyst or equivalent	118	117	104	115	123
Nonleaded tank bottoms	75	82	45	42	53
Biomass	41	32	37	48	41
Primary sludge (F037)	40	NA	NA	NA	NA
Other contaminated soils NOS	31	46	38	69	82
Primary sludge (F038)	26	NA	NA	NA	NA
Other oily sludges/organic residuals NOS	24	13	22	14	8
Residual sulfur	19	17	20	19	16
Residual coke/carbon/charcoal	16	15	28	13	13
All others	23	30	37	56	56
Total	1703	1889	1375	1200	1070
Landspread					
Biomass	23	26	15	48	51
Other oily sludges/organics	13				
Pond Sediments	9	46	1	15	18
Contaminated soils/solids	6	15	16	11	4
Other inorganic residuals NOS	4	8	14	10	11
FCC catalyst or equivalent	2	57	13	1	5
Slop oil emulsion solids	0	1	20	2	4
All others	9	21	16	73	15
Total	66	174	95	160	109
Injection					
Spent caustics	32	32	14	24	33
All others	3	4	1	6	7
Total	35	36	15	30	40
Other methods					
High pH/low pH	54				
All others	6	8	21	2	41
Total	60	8	21	2	41
Grand total	1974	2236	1619	1636	1540

As shown in Table 19, refiners rely on off-site commercial capacity to dispose of residual materials. Refiners used on-site capacity to handle the majority of material disposed for four streams: **high pH/low pH waters, pond sediments, spent caustics,** and **other oily sludges/organic residuals.** It appears, however, that the quantity of an individual stream may help predict where it will be disposed. With the exception of **contaminated soils/solids**, it appears that refiners attempt to manage some of each of the largest streams on-site. Conversely, for the small quantity streams, a greater proportion is handled off-site. In addition, regulatory constraints such as the land disposal restrictions, determine where residuals will be disposed. As indicated below, all of the ash from incineration treatment of **API separator sludge** and **DAF float** was disposed off-site.

Table 19
Location of Disposal Activities
(thousands of wet tons)

Residual Stream	Quantity	% On-Site	% Off-site
Contaminated soils/solids	486	13	87
Pond sediments	337	63	37
Other residuals NOS	274	49	51
Other inorganic residuals NOS	269	25	75
FCC catalyst or equivalent	146	26	74
Spent caustics	33	55	45
Biomass	65	43	57
High pH/low pH waters	54	99	1
Nonleaded tank bottoms	77	9	91
Other oily sludges/organic residuals NOS	37	55	45
Other contaminated soils NOS	31	13	87
Residual sulfur	19	6	94
Residual coke/carbon/charcoal	16	38	62
Other spent catalysts NOS	13	25	75
API separator sludge	5	0	100
DAF float	2	0	100

AQUEOUS MATERIALS

By design, API's survey does not attempt to capture information on refinery wastewater systems. When the survey was initiated, collection of data on material that was substantially dissimilar from the RCRA "solid waste" or its precursors, and/or was regulated under other authorities (e.g., NPDES permits), was considered beyond the scope of effort. Some aqueous materials--those which are disposed (i.e., discarded and handled as a waste) or are regulated under RCRA--met the criteria for inclusion in the survey and are reported below.

Other Aqueous Wastes NOS

As described in Appendix B, the data collected on this residual stream was not considered during the development of an estimation model for the other 29 residual streams. Instead, because of the great variability in the generation quantities, a separate ratio model was used to develop industry estimates of this stream.

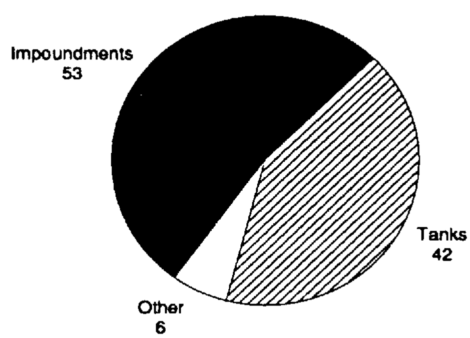
In 1991, 14 refineries reported generating a total of 9.04 million wet tons of **other aqueous residuals** (see Table 3). Of this quantity, 9.03 million wet tons was generated by five facilities that used deep well injection to handle the material. Thus, over 99 percent of the residual is managed by disposal.

Impact of TCLP on Refinery Wastewaters

A new item (Question 8) was added for 1991 to collect information on the amount of refinery wastewater that was identified as characteristically hazardous under RCRA and its subsequent disposition. Of the 113 respondents in the survey, 37 reported that none of their wastewater failed the TCLP. The remaining 76 reported a total of 383.25 million wet tons of wastewater as characteristically hazardous, and therefore subject to specific handling requirements.

As illustrated in Figure O, slightly more than half of the wastewater was handled in RCRA regulated surface impoundments prior to discharge. Another 42 percent was handled in tanks regulated under other authorities and therefore not subject to additional RCRA regulation. Less than 1 percent was deep-well injected, while the remaining 5 percent was handled by "Other" unspecified methods.

Figure O
Techniques Used to Manage TC Hazardous Wastewater (percent of total)



Section 4

DISCUSSION

The 1991 cycle of API's refining survey documented a number of industry achievements:

- a resurgence in the response rate for the survey, bringing representation of the sample to 73 percent of the domestic refining capacity;

- a substantial decrease in the generation of several residual streams (**Other aqueous wastes, pond sediments, API separator sludge, DAF float** and **slop oil emulsion solids**) which, when aggregated with other streams, resulted in the smallest quantity of residuals ever recorded;

- voluntary reporting of pollution prevention activities by an entire industry sector, accounting for over 700 thousand wet tons of material or 5 percent of the total amount of residuals generated;

- a slight drop in recycling residuals, but a reciprocal gain in use of treatment technologies;

- continued diminished use of land treatment, while reliance on disposal did not increase.

The trend analysis performed this year provided additional information on how residuals are generated, supporting identification of several generation patterns: fairly static and likely dependent on throughput (e.g., spent catalysts); successively increasing, such as observed with **spent caustics**; progressively decreasing, as noted with the RCRA listed K-wastes; periodic spikes, such as the peaks in **pond sediments** and **contaminated soils** reported in 1990; and, finally, unpredictable fluctuations that defy interpretation.

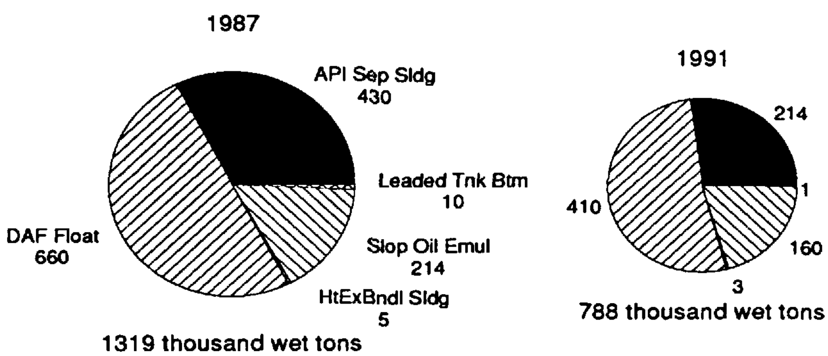
The co-variance analysis, performed on the cohort of 70 refineries that participated in all five survey cycles, replicated the earlier finding that much of the variance in estimates must be attributed to fluctuations at individual refineries. This provides objective, statistical support for the refiners' concern that each refinery is unique and that consideration should be given to site-specific factors.

The 1991 analysis underscored the concern that summary statistics, often used as benchmarks, can be misleading. As seen in the sections on recycling, treatment and land treatment, the aggregated statistics for the industry suggest fairly stable uses of these various technologies. The more detailed information on how individual streams are managed show that there have been substantial changes in how refiners handle residual materials. Recall that for treatment, it appeared that use of wastewater systems simply increased. However, when the stream data was reviewed, it was clear that use of wastewater treatment of wastewater from dewatering oily materials had significantly diminished (which is directly related to the reduction of the amount of this residual generated). This was overshadowed by the increase in the use of wastewater treatment for aqueous chemicals. Thus, individual streams are the more reliable unit for analysis, although they must be viewed in the broader perspective of the individual refinery, where management decisions dynamically balance treatment and storage capacity needs, regulatory constraints and available onsite resources.

Looking at individual streams in 1991 provided an opportunity to assess the sensitivity of the questionnaire and to determine its reliability in measuring industry progress. Specifically, the land disposal restrictions for K-wastes were in effect for all of 1991 and the Best Demonstrated Available Technology (BDAT) requirements dictated how these materials should be handled. These regulations forced the industry to change its handling practices for these streams. API's survey documented these changes, providing quantitative and qualitative information on how the industry met this challenge.

Part of the industry's strategy to comply with these regulations involved a significant reduction in the quantity of these residuals generated. The survey has chronicled this reduction. As shown in Figure P, the quantity of these five streams dropped 67 percent, from 1319 thousand wet tons in 1987 to 788 thousand wet tons in 1991. This included a 50 percent reduction in the amount of **API separator sludge** generated and a 38 percent reduction in **DAF float.**

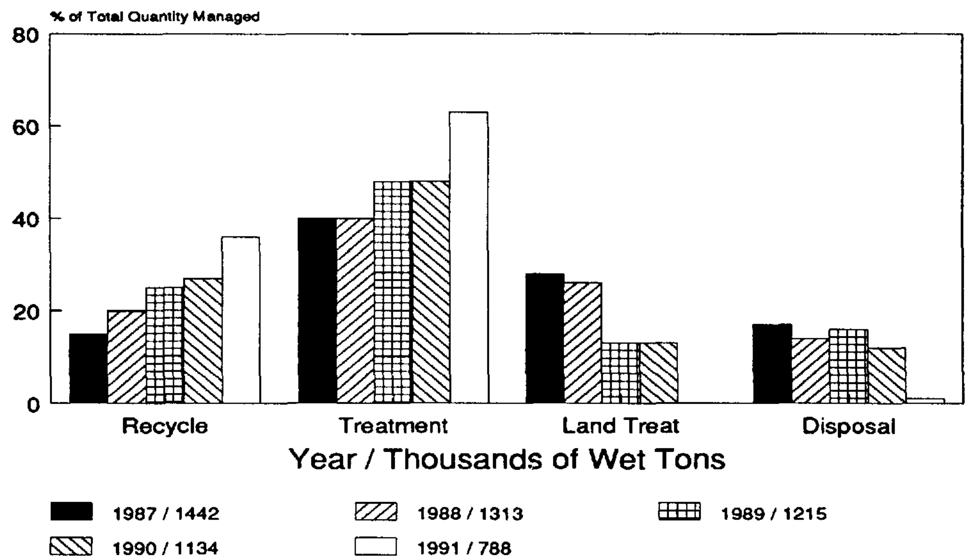
Figure P
Generation of K-Wastes: Comparison of 1987 & 1991



How did the industry achieve these reductions? The data collected on the pollution prevention question provides an answer. As shown in Table 7, the K-wastes of **API separator sludge, DAF float** and **slop oil emulsion solids** were the streams most frequently cited by refiners as targeted for pollution prevention initiatives. Refiners attributed a reduction of over 300 thousand wet tons[6] of these materials to pollution prevention. Moreover, the full panoply of pollution prevention activities were undertaken with these streams. The refiners installed a variety of *new equipment*: thermal dryers, zero sample valves, feed equipment to filter presses. *Procedure modifications* included segregating streams, using safety caps during hot work, and different filtering approaches. Replacing chromates in cooling towers with less hazardous materials was an example of *substitution of raw materials*. Refiners continued to *improve housekeeping* focussing efforts on dust suppression to minimize the entry of particulates into the sewer systems. *In-process recycling* included sending these materials to cokers and crude units, with some innovative reslurrying of filter cake to enable its recycle. In 1991, refiners also reported *out-of-process reclamation* of K-wastes, reusing these materials as fuels for cement kilns or industrial furnaces.

The survey also recorded how the industry changed the way it handled the reduced quantity of K-wastes generated. As shown in Figure Q, the industry increased both recycling and treatment by 20 percent between 1987 and 1991. Land treatment is no longer used and disposal is used for the *de minimis* quantity of ash that remains after incineration treatment.

Figure Q
Management of K-Wastes: 1987 - 1991



There is no question that these concerted efforts were in direct response to the regulatory initiative. But just as the survey has been able to document these efforts, it has also been able to track other efforts by the industry to improve its accounting of residuals.

[6] Note that this is only the amount reported by participating refineries and is not directly comparable to the quantities of residual material estimated for the population of refineries.

Spent caustics serves as a good example. Generation of this stream has increased in each survey cycle. From discussion with respondents it appears that this is really a change in reporting practices, rather than an actual increase in the quantity generated. This may reflect a response to the change in survey terminology, from waste to residual material which promotes reporting of materials that can be beneficially reused.

Throughout the survey refiners have reported recycling approximately 70 percent of the spent caustics generated (See the chart for Spent caustics in Appendix E). In 1991, they continued to sell this residual for re-use in paper and steel manufacturing. The responses to the pollution prevention question revealed that refiners are pursuing new ways of managing this residual. Change-out schedules were modified to diminish generation rates, while companies initiated reuse of caustics onsite to neutralize biotreatment ponds, and off-site, but within the company, as a pre-wash. Although the graphic portrayal of the management practices does not change, the survey information has documented that refiners are exerting effort to improve handling of this stream.

In Appendix E, other improvements in handling practices are noted for several streams:

- recycling and treatment of biomass has increased, with a reciprocal decrease in the use of disposal;
- an increase in recycle of **spent sulfite** and **spent acids**;
- an increase in the recycle of hydroprocessing catalysts.

The tables in Appendix E also highlight some of the streams where there has been little change in management practices. **Contaminated soils/solids** and **pond sediments** both rely on disposal to manage large quantities of residuals. The trend graphs on the top of the pages provide some insight into why this occurs. As noted, the generation quantities for both streams spiked in 1990. While it is understandable that these peaks occur with remediation activities and construction of new units, the generation pattern for these streams is erratic. In addition, as the names of these streams indicate, they are primarily dirt and water, not very valuable substances. Thus, it is hard to find a reuse for these materials, they are not generated routinely enough to warrant research to optimize their treatment, and consequently, disposal remains the only viable management technique.

APPENDIX A
Questionnaire

API ID ______ (Leave Blank)

1) What was the approximate year this facility began operations? Check the appropriate box.

- ☐ Before 1925
- ☐ 1925 - 1940
- ☐ 1941 - 1950
- ☐ 1951 - 1960
- ☐ 1961 - 1970
- ☐ 1971 - 1980
- ☐ After 1980

2) Which of the following USEPA National Pollutant Discharge Elimination System (NPDES) - Permit Fact Sheet Classifications best describes this refinery?

Check the appropriate box

- ☐ **Topping** - Refinery uses topping and catalytic reforming, but <u>not</u> thermal processes or cracking.
- ☐ **Cracking** - Refinery uses topping and cracking, but none of the operations designated in the categories below.
- ☐ **Petrochemical** - Refinery uses topping and cracking, and 1) <u>at least 15%</u> of refinery production is first-generation petrochemicals and isomerization products (e.g., BTX, olefins), or 2) the refinery produces second-generation petrochemicals (e g , alcohols, cumene), and 3) there is <u>no</u> lube oil manufacturing
- ☐ **Lube** - Refinery uses topping, cracking, and lube oil manufacturing processes, but <u>not</u> petrochemical operations.
- ☐ **Integrated** - Refinery uses topping, cracking, lube oil, and petrochemical manufacturing processes.

(NOTE: If your facility does <u>not</u> fit one of these categories, please call Wendall Clark at (914) 227-5769 to clarify the types of operations performed at your facility.)

3) What type of sewer system does this facility have? Check the appropriate box.

- ☐ Non-segregated between process water & storm water
- ☐ Partially segregated between process water & storm water
- ☐ Totally segregated between process water & storm water

4) Indicate your facility's RCRA permitting status and the regulatory authority for the permit. Check the **ONE** category that best describes this facility

- ☐ Generator only; no RCRA permit required. (Hazardous waste is NOT treated, stored or disposed of on-site.)
- ☐ Part A filed (interim status).
- ☐ RCRA permit issued.

5) For 1991, what was this facility's operable crude oil capacity in BARRELS PER STREAM DAY as reported in the Oil & Gas Journal?

__________ Barrels per <u>Stream</u> Day

6) What was the **TOTAL AMOUNT** of crude processed (throughput) in 1991?

__________ Million Barrels

7) In 1991, on how many days was crude charged? __________ Days

NEW TOXICITY (TC) CHARACTERISTIC QUESTIONS (See Page 3 of the Instructions for directions on how to complete these questions)

8) Use spaces below to report the amount of **WASTEWATER** (in WET TONS) that failed the Toxicity Charactersitic (TC) and that was:

TC Hazardous Wastewater

- ☐ Managed SOLELY in tanks exempt from RCRA permitting prior to discharge (TC Wastewater reported here should NOT be reported in any of the following categories)
- ☐ Treated as a TC hazardouse waste in a RCRA permitted surface impoundment prior to discharge
- ☐ Deep well injected
- ☐ Other

ALL RESPONSES TO QUESTION 8 SHOULD BE MUTUALLY EXCLUSIVE; ALSO, DO NOT DOUBLE COUNT TC WASTES IN QUESTIONS 8 & 9

9) In 1991, how much waste, other than wastewater, was handled as TC waste, that had <u>not</u> previously been considered hazardous under RCRA?

__________ wet tons

WASTE CODES FOR API SOLID WASTE SURVEY

OILY SLUDGES AND OTHER ORGANIC WASTES

101 API SEPARATOR SLUDGE (K051)

102 DISSOLVED AIR FLOTATION FLOAT (K048)

103 SLOP OIL EMULSION SOLIDS (K049)

104 LEADED TANK BOTTOMS (K052)

106 POND SEDIMENTS
- Stormwater pond sludge
- Evaporation pond sludge
- Secondary Wastewater Treatment Sludge
- Polishing pond sludge

107 NONLEADED TANK BOTTOMS
- Tank asphalt sludge
- Tank basic sediment sludge (muck/scale)
- Tank cat tar sludge
- Tank clarified oil sludge
- Tank crude sludge (muck/scale)
- Tank product sludge(muck/scale)
- Tank other sludge

108 WASTE OILS/SPENT SOLVENTS
- Benzene
- Naphtha
- Specialty oil, waste
- Toluene
- Waste oil, (not used)
- Waste oil, (used)

109 OTHER OILY SLUDGES & ORGANIC WASTES NOS
- Desalter sludge
- HF acid tars
- Scrapper trap waste (PL pigging sludge)
- Other organic sludges, NOS above
- Tetraethyl lead
- Spent additive (gasoline)
- Other organic liquids, NOS

110 PRIMARY SLUDGE (Gravitational separation - FO37)
- Separator sludge, other
- Equalization pond sludge
- Pretreatment sludge

111 PRIMARY SLUDGE (Physical/chemical separation - FO38)
- Induced Air Flotation (IAF) Float
- Other Separator sludge

CONTAMINATED SOIL/SOLIDS

201 HEAT EXCHANGER BUNDLE CLEANING SLUDGE (K050)

202 CONTAMINATED SOILS/SOLIDS
- Soil (crude) contaminated
- Soil (product) contaminated
- Debris, contaminated
- Used Sand Blasting Grit

203 WASTE COKE/CARBON/CHARCOAL
- Activated carbon
- Carbon black
- Charcoal
- Coke chunks
- Filter media, activated carbon
- VRU charcoal

204 WASTE SULFUR
- Claus unit waste
- Contaminated sulfur
- Sulfur with Stretford contamination

205 OTHER CONTAMINATED SOILS
- Activated alky alumina
- Activated alumina
- Asphalt spill
- Catacarb filter media
- Stretford solution
- Filter sand
- Filter clay
- Grit trap waste
- Oil (crude) spill, non-soil
- Oil (product) spill debris, non-soil
- Tank bottoms, absorbent materials
- Waste oil absorbents
- Wax, contaminated
- Other contaminated soilds, NOS above

WASTE CODES

SPENT CATALYSTS

301 FLUID CRACKING CATALYST OR EQUIVLAENT
- FCCU cat dust
- Spent FCCU cat
- Contaminated FCCU cat

302 HYDROPROCESSING CATALYSTS
- Metallic catalysts

303 OTHER SPENT CATALYSTS
- Reformer catalysts
- Shift converter catalysts
- Other metallic catalysts, NOS
- Other spent catalysts, NOS

AQUEOUS WASTES

401 BIOMASS
- Biox Sludge

402 OIL CONTAMINATED WATERS OTHER THAN WASTEWATER
- Miscellaneous aqueous liquids
- Water, contaminated - oil, gasoline, etc.
- Bilge water

403 HIGH PH/LOW PH WATERS
- Ammonia & water

404 SPENT SULFITE SOLUTION

405 SPENT STRETFORD SOLUTION

406 OTHER AQUEOUS WASTE NOS
- (Do not include refinery process and/or storm wastewater)

407 TSD LEACHATE (F039)

CHEMICALS/INORGANIC WASTES

501 SPENT CAUSTICS
- Caustics, cresylic
- Caustics, sulfidic

502 SPENT ACIDS
- Acids, spent
- Sulfuric acid (excluding that exempted under CFR 261.4 (a)(7))

503 WASTE AMINES
- Amine sludges
- Amine reclaimer sludges
- Spent amines
- Other amine wastes, NOS

504 OTHER INORGANIC WASTES NOS
- Boiler feed treatment sludge
- Caustic tank sludge
- Cleaners, acid
- Cleaners, caustic
- Cooling tower sludge
- Ion exchange resin
- Iron sulfide rust sludge
- Lime sludge, water treatment
- Lime sludge, alky
- Inorganic liquids, NOS
- Inorganic sludges, NOS

OTHER WASTES

601 OTHER WASTES
- Asbestos insulation
- Drums, empty
- Lab/sample container, empty
- Laboratory wastes
- Batteries
- Butyl mercaptan
- Cement
- Desiccant, air drier
- Fiberglass
- Filter cartridges
- Filter, turbo fuel
- Oily rags
- Paint waste
- PCB capacitors
- PCB transformers
- PCB liquid
- Other listed wastes, NOS
- Other organic gases, NOS

WORKSHEET & CODES FOR FACING DATA SHEET

INPUTS

GENERATION

ROUTINE - wastes generated periodically, but according to some schedule (e.g., weekly; semi/ bi-annually; every five years)

ABNORMAL- aperiodic or unusual waste generation, such as when a unit is built or closed, or when general remediation or a spill occurs

OUTPUTS

RECYCLE/REUSE CODES

R -	Onsite	Offsite
In-Process Recycle		
Coker	200	201
Crude Unit	210	211
Desalter	220	221
Cat Cracker	230	231
Other	960	961
Out-of-Process/non-fuel Reuse		
Cement Kiln Feed	270	271
Other	970	971
Industrial Fuel		
Cement kiln	280	281
Other(blast furnace)	980	981
Reclamation	250	251
Regeneration	260	261
Other	920	921

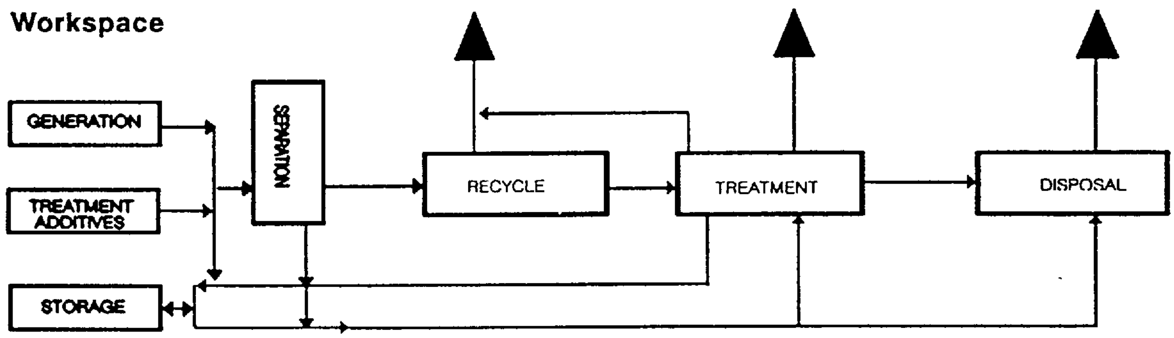
TREATMENT CODES

T -	Onsite	Offsite
Weathering	310	311
Chemical	330	331
Heat	340	341
Impoundment	370	371
Physical	380	381
Wastewater Treatment	390	391
Incineration	400	401
Land Treatment	410	411
Stabilization/ Fixation	420	421
Other	940	941

DISPOSAL CODES

D -	Onsite	Offsite
Impoundment	500	501
Landfill	510	511
Landspread	520	521
Injection	530	531
Other	950	951

Workspace



POLLUTION PREVENTION is a multimedia concept that reduces or eliminates pollutant discharges to air, water or land and includes the development of more environmentally acceptable products, changes in processes and practices, source reduction, beneficial use and environmentally sound recycling. Categorize the type of pollution prevention activity performed according to the codes listed below. (The responses to this question will be treated independently from those reported above; it is likely that you will be reporting some of the same activities under the Recycle sections above.)

1 - Equipment or technology modifications
2 - Procedure modifications
3 - Reformulation or redesign of products
4 - Substitution of raw materials
5 - Improved housekeeping; training of personnel or inventory control procedures

In-process RECYCLE
6 - In refining process units (e.g., crude unit; coker; desalter etc)
7 - Recovering oil (& dewatering) by filter pressing/centrifugation
8 - Other recycle

Out-of-process RECYCLE
9 - Reuse/reclamation
10 - OTHER. Describe in comment section.

CALCULATIONS

API ID#__________
(LEAVE BLANK)

DID YOUR FACILITY GENERATE/MANAGE: **CODE 101 API SEPARATOR SLUDGE (K051)** ________ (YES/NO)

WASTE MANAGEMENT

INPUTS		OUTPUTS						
GENERATION	WET TONS	SEPARATION TECHNIQUES	ELIMINATED BY RECYCLE		ELIMINATED BY TREATMENT		DISPOSAL	
		Check any performed	WET TONS	CODE	WET TONS	CODE	WET TONS	CODE
ROUTINE	____	Decanting __	____	R ____	____	T ____	____	D ____
ABNORMAL	____	Thickening __	____	R ____	____	T ____	____	D ____
HAVE THESE GENERATION QUANTITIES HAD PRIOR DEWATERING? ☐ YES ☐ NO		Centrifugal __	____	R ____	____	T ____	____	D ____
TREATMENT ADDITIVES	____	Filtration __	____	R ____	____	T ____	____	D ____
STORAGE REMOVED FROM	____		____	R ____	____	T ____	____	D ____
PLACED INTO -	(____)							
TOTALS	☐	=	☐		+ ☐		+ ☐	

PLEASE CHECK TO MAKE SURE EQUATION BALANCES.

POLLUTION PREVENTION

Did your refinery conduct any activities, change any practices or modify any equipment that **DECREASED** the amount of this waste stream generated or requiring disposal in 1991?

____ No ____ Yes - Enter amount reduced, ________wet tons, circle the appropriate waste prevention method code below (see facing page for codes) and provide a brief description of the method used:

Code	Description:
1 2 3 4 5 6 7 8 9 10	Activity 1. Year 19__ __ __________
1 2 3 4 5 6 7 8 9 10	Activity 2. Year 19__ __ __________
1 2 3 4 5 6 7 8 9 10	Activity 3. Year 19__ __ __________

Description of ABNORMAL Generation event, and/or codes categorized as "Other".

Comments/Calculations:

APPENDIX B
Statistical Procedures

1.0 INTRODUCTION

The objective of this appendix is to provide a detailed description of the statistical methodology utilized in obtaining the estimated residual quantities presented in the main body of the report. Regression analysis was used for estimating the total generated quantity of residual material in the U.S. The generated quantities for individual streams were then estimated by apportioning to each stream that percent of total generated quantity as was obtained from the respondents. Variances for the total generated quantity and individual stream quantities were calculated as a measure of preciseness of the estimates. Details of these statistical procedures follow.

2.0 ESTIMATION OF TOTAL QUANTITY GENERATED

2.1 MODELLING

Regression analysis was used to estimate the residual quantity generated by the industry. There were 113 respondent refineries and 70 non-respondents in 1991. The 113 respondents had a total capacity of 12,073,901 barrels per stream day representing approximately 73% of the refining capacity of the United States. The regression model that best fit the data was obtained and was used to estimate residual quantities for the non-respondents.

There was one major difference in the 1991 modelling and estimation procedure as compared to the previous years. The residual stream consisting of Other Aqueous Residuals NOS was excluded from all modelling and estimation. The reasons for this are: (1) This one residual stream alone has accounted for approximately 60% of total residual material generated over the 5 survey years and (2) With approximately 99% of this stream being deep-well injected, it is handled quite differently from the other streams. This is a low-frequency, high-volume stream. In 1991, only 12% of the respondents generated this stream but accounted for 66% of total residual quantity generated. Thus, in 1991, Other Aqueous Residuals NOS was handled separately from the other streams.

Data were analyzed to evaluate the effect of different factors on residual quantity generated by a refinery. The factors considered were operable crude capacity of a refinery (barrels per stream day), age, type and sewer system. Scatter-plots were developed to help explore the relationships between residual quantity generated and the various factors thought to be affecting it. Individual factors were evaluated as well as combinations of factors. Like previous years, the strongest correlation observed in the data was a positive correlation between operable crude capacity and residual generation. Simple and multiple linear regression models were considered. But combining other factors with operable crude capacity did not significantly improve the predictive capability of the model.

Scatter-plots were also used to find and quantify the form of capacity that best captured its relationship with residual quantity generated. Regression models were obtained for different forms of capacity and residual quantity generated. The regression models were evaluated based on performance criteria like R^2 and Root Mean Squared Error (RMSE). The R^2 is a measure of fit of the model. It represents the proportion of variation in the response data explained by the model. The fit of the model to the data is perfect if $R^2=1$ ($0 \le R^2 \le 1$). The

RMSE is also a measure of quality of fit and it represents the variance due to model error i.e. variability unexplained by the model. Evaluation was also based on how closely model assumptions on normality of residuals and homogenous variance of residuals were followed.

After examining the regression models, scatter-plots and correlations, it was found that the best relationship was between capacity and square root of total residual quantity generated.

Thus, the following simple linear regression model was obtained with capacity as the explanatory variable.

$$\sqrt{Total\ Residual\ Quantity\ Generated} = A + B\ (Capacity)$$

where A and B are estimated from the regression model.
After making reverse transformations to obtain the total residual quantity generated, the corresponding regression diagnostics were: $R^2 = 0.75$ and Root Mean Squared Error = 27,256 wet tons. The R^2 value of 0.75 is quite good given the highly variable nature of the data. Also, the RMSE of 27,256 wet tons was the best among all competing models.

2.2 OUTLIERS

Six outliers were identified during the modelling procedure. Outliers are individual observations that do not follow the general trend of the data and being influential observations they tend to distort the model. Deleting outliers from the model results in a better fit since the outliers tend to pull the regression towards them. The six facilities were identified as outliers based on the R-student statistic and their influence on the regression diagnostics.

These outliers were excluded only while obtaining the best model that was used for estimating the residual quantity generated by the non-respondents. Outliers were included at all other stages of the estimation procedure.

The 6 outliers identified in 1991 have a total capacity of 1,048,500 barrels per stream day and the total residual quantity generated by them is 805,737 wet tons. We have a fairly balanced list of outliers with 3 outliers each at the high and low end of the data.

2.3 ESTIMATION

In 1991, 4,351,646 wet tons of residual material were generated by the 113 survey respondents for 29 residual streams. Regression analysis was used for estimating generation quantities of non-respondents because it was the only statistical tool that best utilized the relationship between residual generated and capacity such that residual generated could be predicted based on capacity. Ratio estimation was also considered but not used because (1) performance criteria like R^2 and RMSE were not as good as those obtained for the regression model and (2) the response data do not fully satisfy the following 2 assumptions required for this method: (2a) the relationship between residual quantity generated and capacity is a straight line through the origin and (2b) the variance of residual quantity generated about this line is proportional to capacity.

The regression model obtained was used to estimate the residual quantity generated by each of the 70 non-respondents. The assumption made here is that the factors influencing residual generation for respondents are similar to those for non-respondents. Because of the square root transformation, this model yields a biased estimate of the residual quantity generated and its variance. Therefore, a bias correction factor has to be applied.

The regression model is:

$$\sqrt{\hat{Y}} = a + b\ [\text{Capacity}]$$

where $\hat{Y}$ = Estimated residual quantity generated.

Taking the expected value,

$$E(\hat{Y}) = E(\sqrt{\hat{Y}}^2) = (\sqrt{\hat{Y}})^2 + \text{Variance}(\sqrt{\hat{Y}}).$$

That is, the estimate of residual quantity generated cannot be obtained by simply squaring the estimate obtained from the model. Hence the following bias correction had to be made:

$$\text{Estimate of residual quantity generated, } \hat{Y} = (\sqrt{\hat{Y}})^2 + \text{Variance}(\sqrt{\hat{Y}}).$$

Also, variance of the estimated residual quantity generated by each non-respondent after correction for bias is:

$$\text{Variance (Estimated residual quantity generated generation)} = \text{Variance}(\hat{Y}) = 4 \times (\sqrt{\hat{Y}})^2 \times \text{Variance}(\sqrt{\hat{Y}}) + 2 \times [\text{Variance}(\sqrt{\hat{Y}})]^2$$

Details on variance estimation for estimated total quantity generated are given in Section 5.1.

The estimated residual quantities for the non-respondent refineries were then added to obtain the total quantity of residual material generated by all 70 non-respondents. This was estimated to be 1,457,690 wet tons.

Estimated total residual quantity = Residual quantity generated by respondents + Estimated Residual quantity generated by non-respondents.

Therefore, for 29 residual streams, the estimated total quantity of residual material generated in 1991 by 183 refineries = 4,351,646 + 1,457,690 = **5,809,336 wet tons.**

The average residual quantity generated by respondents was 38,510 wet tons and by non-respondents was 20,824 wet tons. This discrepancy in average quantity generated by respondents and non-respondents is due to the fact that most of the refineries captured by the survey had large operating capacities. Whereas, the non-respondents mainly consisted of refineries with smaller capacities.

NOTATION FOR SECTIONS 3.0 - 5.0.

FOR AN INDIVIDUAL RESIDUAL STREAM:

R_Generated = Residual quantity generated by all respondents.

N_Generated = Estimated residual quantity generated by all non-respondents.

T_Generated = Estimated residual quantity generated by respondents + non-respondents.

R_Treatment Additives = Amount of treatment additives added by respondents.

N_Treatment Additives = Estimated amount of treatment additives added by non-respondents.

R_Net from Storage = Net quantity removed from storage by respondents.

N_Net from Storage = Net quantity removed from storage by non-respondents.

R_Managed = Residual quantity managed by all respondents.

N_Managed = Estimated residual quantity managed by all non-respondents.

T_Managed = Estimated residual quantity managed by respondents + non-respondents.

R_Recycled/Treated/Land treated/Disposed = Quantity of residual material recycled/treated/land treated/disposed by respondents.

N_Recycled/Treated/Land treated/Disposed = Estimated quantity of residual material recycled/treated/land treated/disposed by non-respondents.

R_i _Recycled = Residual quantity recycled using ith specific practice by respondents.

T_i _Recycled = Estimated residual quantity recycled using ith specific practice by respondents + non-respondents.

FOR ALL 29 STREAMS:

Total R_Generated = Total residual quantity generated by all respondents.

Total N_Generated = Estimated total residual quantity generated by all non-respondents.

Total R_Generated = Estimted total residual quantity generated by respondents + non-respondents.

FOR AN INDIVIDUAL REFINERY/STREAM COMBINATION:

i = ith residual stream

j = individual respondent refinery

R_Generated$_{ij}$ = Residual quantity generated by jth respondent refinery for ith stream.

3.0 ESTIMATION OF INDIVIDUAL STREAM QUANTITIES

In 1991, the estimated total quantity of residual material generated for 29 residual streams was 5,809,336 wet tons. A detailed explanation of the estimation procedure for calculating individual residual stream quantities is given below. The estimation steps given are for an individual residual stream and these steps remain the same for all 29 streams. The assumptions made here are: (i) residual quantity generated for a particular stream is not a function of refinery capacity and (ii) for respondents, the overall proportion of generated residual quantity for a particular stream is same as that for non-respondents.

(a) For the 113 respondent refineries, the ratio of residual quantity generated by stream *to* the total quantity of residual material generated for all streams was calculated.

That is, for respondents,

$$\text{R\_Ratio} = \frac{\text{R\_Generated}}{\text{Total R\_Generated}}$$

This proportion is then applied to the total estimated residual quantity generated by all non-respondents to get the residual quantity generated, by stream, for non-respondents.

$$\begin{array}{l}\text{Estimated residual} \\ \text{quantity generated} \\ \text{by non-respondents,} \\ \text{by stream}\end{array} = \text{N\_Generated} = \text{R\_Ratio} \times \text{Total N\_Generated}$$

(b) The residual quantity *managed* by respondents is,

$$\begin{array}{c}\text{R\_Managed} \\ \text{Quantity}\end{array} = \text{R\_Generated} + \text{R\_Treatment Additives} + \text{R\_Net from storage.}$$

This constitutes the input quantity of residuals.

To estimate the residual quantity *managed* by non-respondents, treatment additives and net quantity from storage have to be estimated for non-respondents.

For respondents, each stream's proportion of treatment additives and net quantity from storage is calculated.

$$\text{R\_Ratio Treatment Additives} = \text{R\_Treatment Additives} \div \text{R\_Generated}$$

$$\text{R\_Ratio Net from Storage} = \text{R\_Net from Storage} \div \text{R\_Generated}$$

These proportions are then applied to the residual quantity generated by stream, by the non-respondents, to obtain estimated amount of treatment additives and net quantity from storage.

Amount of treatment additives added to a stream for non-respondents:

$$\text{N\_Treatment Additives} = \text{R\_Ratio Treatment Additives} \times \text{N\_Generated.}$$

Net quantity of residual material removed from storage and added to a stream for non-respondents:

$$\text{N\_Net from Storage} = \text{R\_Ratio Net from Storage} \times \text{N\_Generated.}$$

Managed quantity of residual material for non-respondents:

$$\text{N\_Managed Quantity} = \text{N\_Generated} + \text{N\_Treatment Additives} + \text{N\_Net from storage}$$

Total quantity of residual material managed by respondents and non-respondents, by stream:

$$\text{T\_Managed Quantity} = \text{R\_Managed Quantity} + \text{N\_Managed Quantity} \quad \{1\}$$

Therefore, the estimated amount of residual material managed in all 29 residual streams is obtained by summing the managed quantity in {1} over all streams:

$$\sum \text{T\_Managed Quantity} = 5{,}808{,}218 \text{ wet tons.}$$

4.0 ESTIMATION OF INDIVIDUAL STREAM QUANTITIES

4.1 BY MANAGEMENT TECHNIQUE

As in the previous section, the estimation steps presented below are for an individual residual stream and these steps remain the same for all 29 streams.

The input quantity of residual material is handled by the different management techniques - this constitutes the output. The inputs should equal the outputs.

$$\text{Generated Quantity} + \text{Treatment Additives} + \text{Net From Storage} = \text{Recycle} + \text{Treatment} + \text{Disposal}$$

For non-respondents, quantities of residual material that were recycled, treated, land treated and disposed have to be estimated.

For respondents, total managed quantity is,

R_Managed Quantity = R_Recycled + R_Treated + R_Land Treated + R_Disposed

As before, the proportion of each technique is obtained for respondents and then applied to the non-respondent input quantity of residuals to get a break-up by stream, and by management technique, for non-respondents.

R_Ratio Recycled = R_Recycled ÷ R_Managed Quantity
R_Ratio Treated = R_Treated ÷ R_Managed Quantity
R_Ratio Land Treated = R_Land Treated ÷ R_Managed Quantity
R_Ratio Disposed = R_Disposed ÷ R_Managed Quantity

Therefore the *non-respondent* quantity of residuals that is recycled, treated, land treated and disposed (by stream) is:

Quantity of residual material recycled by non-respondents = N_Recycled = R_RatioRecycled × N_Managed Quantity

Quantity of residual material treated by non-respondents = N_Treated = R_Ratio Treated × N_Managed Quantity

Quantity of residual material land treated by non-respondents = N_Land Treated = R_Ratio Land Treated × N_Managed Quantity

Quantity of residual material disposed by non-respondents = N_Disposed = R_Ratio Disposed × N_Managed Quantity

And, total managed quantity, for non-respondents, is:

N_Managed Quantity = N_Recycled + N_Treated + N_Land Treated + N_Disposed

Total quantity of residual material managed by respondents and non-respondents is:

Managed Quantity = R_Managed Quantity + N_Managed Quantity {2}

The managed quantities of residual material in {1} and {2} are equal.

The estimated amount of residual material managed in all 29 streams is obtained by summing the managed quantity over all streams:

$$\Sigma\ T\_Managed\ Quantity = 5{,}808{,}218 \text{ wet tons.}$$

4.2 BY SPECIFIC PRACTICES

The estimated residual quantities handled by recycling, treatment and disposal are obtained. Each of these techniques is further broken down into the following sub-categories.

Recycling: coker, crude unit, desalter, catalytic cracker, other in-process recycle, cement kiln(out of process), other out of process, cement kiln(industrial fuel), other industrial fuel, reclamation, regeneration and other.

Treatment: weathering, chemical, heat, impoundment, physical, wastewater treatment, incineration, stabilization/fixation, and other.

Disposal: disposal impoundment, landfill, landspread, injection and other.

The residual quantities handled by these specific practices have to be estimated for the population. This procedure is outlined below by stream, for recycling, and is similar for treatment and disposal.

(a) For respondents, the ratio of residual quantity recycled using ith specific practice to the total residual quantity recycled by stream is calculated.

$$R_i\_Ratio = R_i\_Recycled \div R\_Recycled$$

(b) This ratio is applied to the total estimated residual quantity recycled by respondents and non-respondents to obtain the estimated quantity recycled by ith specific practice for the population.

$$T_i\_Recycled = R_i\_Ratio \times T\_Recycled.$$

Similarly, the estimated quantities of residual material recycled by the other 11 recycling sub-categories is calculated for each stream.

Steps (a) and (b) are repeated for treatment and disposal techniques to obtain estimated residual quantities handled by different practices .

5.0 VARIANCE ESTIMATION

5.1 VARIANCE ESTIMATION FOR ESTIMATED TOTAL GENERATED QUANTITY OF RESIDUAL

In 1991, the total estimated residual quantity generated by 183 refineries for 29 streams was 5,809,336 wet tons. The variance for this estimated quantity was calculated as a measure of preciseness of the estimate. The variance was also used in constructing an approximate 95% confidence interval for the estimated residual quantity.

Total T_Generated = Total R_Generated + Total N_Generated = 5,809,336 wet tons

Variance(Total T_Generated) = Variance(Total R_Generated) + Variance(Total N_Generated)

But Variance(Total R_Generated) = 0 since the residual quantity generated by respondents is known. Therefore, Variance(Total T_Generated) = Variance(Total N_Generated)

The variance of the estimated residual quantity generated by all non-respondents is obtained by summing the individual prediction variances for each of the non-respondent refineries. The prediction variances for each of the 70 non-respondent refineries is obtained from the regression model into which its capacity is inputted to estimate its generated residual quantity.

Variance(Total T_Generated) = Variance(Total N_Generated) = 23,259,163,689.

Standard Error(Total T_Generated) = $\sqrt{}$Variance(Total T_Generated) = 152,509 wet tons

Percent Error of estimated total generated quantity = $\dfrac{2 \times \text{Standard Error}}{\text{Estimated residual quantity}} \times 100$

The percent error reflects the relative margin of error of the estimate and it corresponds to a 95% confidence interval. In 1991, the estimated total generated residual quantity was 5,809,336 wet tons and its margin of error is ±5.2%. That is, we are 95% confident that the true total generated quantity lies in the interval [5,507,250 tons 6,111,421 tons].

5.2 VARIANCE ESTIMATION FOR INDIVIDUAL STREAM QUANTITIES

The estimated residual quantity generated by stream is :

T_Generated = R_Generated + N_Generated

Variance of this estimated residual quantity for a stream is:

$$\text{Variance(T\_Generated)} = \text{Variance(R\_Generated)} + \text{Variance(N\_Generated)} = \text{Variance(N\_Generated)}$$

since the residual quantity generated by respondents is known.

From Section 3.0 on estimation of individual stream quantities,

Estimated residual quantity generated by non-respondents = N_Generated = R_Ratio × Total N_Generated Variance(N_Generated) = Variance(R_Percent × Total N_Generated)

> For any 2 independent variables Y and Z,
> $\text{Variance}(Y \times Z) = \mu_Y^2 \times \text{Var}(Z) + \mu_Z^2 \times \text{Var}(Y) + \text{Var}(Y) \times \text{Var}(Z)$

Therefore,

$$\text{Variance(T\_Generated)} = \text{Variance(N\_Generated)} = \text{R\_Ratio}^2 \times \text{Var(Total N\_Generated)} + [\text{Total N\_Generated}]^2 \times \text{Var(R\_Ratio)} + \text{Var(R\_Ratio)} \times \text{Var(Total N\_Generated)}$$

Total estimated residual quantity generated by all non-respondents = Total N_Generated = 1,456,332 wet tons

Variance(Total N_Generated) = 23,259,163,689

Calculation of Variance(R_Ratio):

For respondents,

$$\text{R\_Ratio} = \frac{\text{R\_Generated}}{\text{Total R\_Generated}}$$

which can be written as:

That is, R_Ratio can be written as a weighted sum of the ratio,

$$R_{ij} = \frac{\text{R\_Generated}_{ij}}{}$$

$$R\text{-}Ratio = \frac{\Sigma_j\ R\text{-}Generated_{ij}}{\Sigma_i\ \Sigma_j\ R\text{-}Generated_{ij}}$$

$$= \Sigma_j \left[\frac{\Sigma_i\ R\text{-}Generated_{ij}}{\Sigma_i\ \Sigma_j\ R\text{-}Generated_{ij}} \times \frac{R\text{-}Generated_{ij}}{\Sigma_i\ R\text{-}Generated_{ij}}\right]$$

$\Sigma_i R\_Generated_{ij}$

where the weight, $W_j = \dfrac{\Sigma_i\ R\_Generated_{ij}}{\Sigma_i\ \Sigma_j\ R\_Generated_{ij}}$.

So, $R\_Ratio = \Sigma_j\ (W_j \times R_{ij})$

$Variance(R\_Ratio) = \Sigma_j\ W^2_j \times Variance(R_{ij})$ and

$\Sigma\ W_j^2 = 0.035914$

$$Var(R_{ij}) = \frac{USS - \frac{(\Sigma R_{ij})^2}{n}}{n(n-1)}$$

where USS = Uncorected Sum of Squares of (R_{ij}) and
n = # of respondent refineries for a stream.

For each residual stream, facilities with $\dfrac{[R_{ij} - Mean(R_{ij})]}{Standard\ Deviation(R_{ij})}$ greater than 4

were deleted from the variance calculation . The rationale behind it is that for a normal distribution, nearly 100% of the observations would fall within 4 Standard Deviation units of the mean. The observations that were greater than 4 S.D's from the mean are similar to outliers and are thus deleted while calculating Variance(R_Ratio).

The following page contains (1) estimated generated quantity for each residual stream, (2) the variance of this estimated generated quantity and (3) the percent error for estimated generated quantity for each residual stream.

6.0 ESTIMATION OF OTHER AQUEOUS RESIDUALS NOS

Notation:

i refers to an individual respondent refinery.

N = # of refineries in population = 183

n = # of respondent refineries = 113

$R\_Generated_i$ = Quantity of Other Aqueous Residuals NOS generated by an individual respondent refinery.

$R\_Capacity_i$ = Capacity of an individual respondent refinery.

R_Generated = Total quantity of Other Aqueous Residuals NOS generated by all respondent refineries.

R_Capacity = Total capacity of all respondent refineries.

T_Generated = Total estimated quantity of Other Aqueous Residuals NOS generated by all refineries (respondents + non-respondents).

T_Capacity = Total capacity of all refineries (respondents + non-respondents).

In 1991, among the respondents, a total of 14 facilities generated 9,035,672 wet tons of Other Aqueous Residuals. The total capacity of these 14 refineries is 2,345,829 barrels per stream day. Of these 14 facilities, 5 disposed of their generated quantity of Other Aqueous Residuals by deep-well injection.

Ratio estimation was used to obtain quantities of Other Aqueous Residuals generated by all 183 refineries. In estimating the Other Aqueous Residuals NOS generated by all refineries, it was assumed that none of the non-respondents practice deep-well injection and hence, none of them generate very large quantities of this stream. API consulted the following two sources to confirm that none of the non-respondents practice deep-well injection: 1) The RCRA Biennial Survey (1989) and 2) Toxic Release Inventory (1991). The top 40 facilities with the highest generated residual quantities for each state are given in the RCRA Biennial survey. None of our non-respondents are present among the top 40 generators as practicing deep-well injection. The Toxic Release Inventory gives a list of all chemicals that are disposed by underground injection by refineries in the U.S. None of the non-respondents were listed in the TRI as having practiced deep-well injection in 1991.

Thus, the 5 respondent refineries that used deep-well injection were left out of the estimation procedure but were later added back to the estimated generated quantity. In effect, they were treated like outliers.

According to the ratio estimation method, Estimated quantity of Other Aqueous Residuals generated by 178 refineries is:

$$\frac{R\_generated}{R\_Capacity} \times T\_Capacity$$

After adding back residual quantities for the 5 refineries that used deep-well injection, the estimated amount of Other Aqueous Residuals generated by all 183 refineries is,

T_Generated = **9,040,062 wet tons**

Variance (T_Generated Quantity)

$$= \frac{N^2}{n(n-1)} (1 - \frac{n}{N}) \sum [\textit{R-Generated}_i - (\frac{\textit{R-Generated}}{\textit{R-Capacity}}) \textit{R-Capacity}_i] 2 \quad = \mathbf{40{,}998{,}409}$$

Standard Error (T_Generated Quantity) =

$$\sqrt{Variance(T\text{-}Generated\ Quantity)} = \mathbf{6{,}403}\ \textit{wet tons}$$

7.0 TREND ANALYSIS

For each residual stream, the estimated generated quantity and its approximate 95% confidence interval was plotted for all 5 years. The approximate 95% confidence interval for the estimated generated quantity is,

Estimated Generated Quantity ± 2 Standard Error

If there is no overlap in the confidence intervals from one year to another, as an approximate rule of thumb, it can be said that the differences in the generated residual quantities *are* significantly different at 95% confidence level.

The following 13 streams showed significant *decreases* in 1991 when compared to 1987: API Separator Sludge, DAF Float, Slop Oil Emulsion Solids, Leaded Tank Bottoms, Other Contaminated Soils NOS, Hydroprocessing Catalysts, Other Spent Catalysts NOS, Spent Sulfite Solution, Spent Stretford Solution, Nonleaded Tank Bottoms, High ph/Low ph waters, Spent Acids and Other Aqueous Residuals NOS.

The following 11 streams showed significant *increases* in 1991 when compared to 1987: Contaminated Soil/Solids, Fluid Cracking Catalyst or Equivalent, Biomass, Spent Caustics, Other Inorganic Residuals NOS, Other Residuals NOS, Residual oils/Spent Solvents, Other Oily Sludges and Organic Residuals, Residual Coke/Carbon/Charcoal, Oil Contaminated water

NOT Wastewater and Residual Amines.

The following 3 streams did not show any significant changes when compared to 1987: Pond Sediments, Heat Exchanger Bundle Cleaning Sludge and Residual Sulfur.

From the graphs for the listed hazardous wastes, the effect of the RCRA land-ban is apparent as a decreasing trend. Trend graphs were not plotted for Primary Sludge(F037), Primary Sludge(F038), and TSD Leachate since these 3 streams were incorporated in the survey in 1991.

8.0 COEFFICIENT OF VARIATION ANALYSIS

Seventy refineries participated in all five survey years. A coefficient of variation analysis was performed on these seventy refineries to assess the magnitude of differences in variation between individual refineries and all seventy refineries combined, over the 5 survey years.

For these seventy refineries, residual streams with 5-year industry-wide means of at least 100,000 wet tons were chosen for the analysis. There are 10 such streams and for these streams, the coefficient of variation for all 70 refineries combined as well as for individual refineries was calculated. The coefficient of variation is a measure of relative dispersion and is used here for comparing variation in the total generated quantity for all 70 refineries over 5 years as opposed to variation in the generated quantities of individual refineries over 5 years.

The coefficient of variation is calculated as follows:

Let T_Generated = Combined generated quantity of all 70 refineries in a year.
R_Generated = Generated quantity of an individual refinery in a year.

For a residual stream:

(i) Coefficient of variation for the combined generated quantity of all 70 refineries:

$$\text{Coefficient of Variation} = \frac{\text{Standard Error(T\_Generated)}}{\text{Mean(T\_Generated) over the 5 year period}}$$

(ii) Coefficient of variation for an individual refinery:

$$\text{Coefficient of Variation} = \frac{\text{Standard Error(R\_Generated)}}{\text{Mean(R\_Generated) over the 5 year period}}$$

For a residual stream, the coefficient of variation for each refinery is calculated and the median C.V. of these refineries is derived.

Table I gives the C.V. for the combined generated quantity of 70 refineries and the median C.V's for individual refineries.

Table I

Coefficient of Variation for combined residual quantity generated by 70 refineries and for residual quantity generated by individual refineries.

Residual Stream	5-year mean of combined residual qty. generated by 70 refineries	C.V. for combined residual quantity of 70 refineries	Median C.V. for individual refineries
API Separator Sludge	213,221	50%	91%
DAF Float	280,414	14	77
Slop Oil Emulsion Solids	126,840	32	134
Pond Sediments	303,949	58	199
Contaminated Soil / Solids	329,275	67	122
Fluid Cracking Catalyst	105,776	19	51
Biomass	455,540	11	109
Spent Caustics	508,084	17	85
Other Inorganic Residuals	225,172	27	93
Other Residuals	220,029	29	98

The C.V.'s for the combined generated quantity range from 11% to 67% whereas the median C.V.'s for individual refineries range from 51% to 199%. Thus, it is apparent that the C.V.'s for individual refineries are much higher. This is indicative of the fact that residual generation rates vary more from year to year within facilities than for the industry as a whole. This then suggests that industry-wide measures of change have to be quite substantial in order to be able to detect meaningful progress for the industry as a whole.

Variance by Stream for 1991 1

Waste Stream	Genper-% generated	Variance of Genper	Total gen(r+nr)	Stream Variance	Std.Err	2SE	Percent Error
101	0.03609	.000004973	209676.43	40812507.72	6388.47	12776.93	6.0936
102	0.06989	.000002900	405995.11	119199171.23	10917.84	21835.67	5.3783
103	0.02846	.000001093	165329.92	21082321.59	4591.55	9183.10	5.5544
104	0.00012	.000000013	714.21	27533.84	165.93	331.87	46.4661
106	0.06410	.000007089	372400.48	110275339.67	10501.21	21002.41	5.6397
107	0.01877	.000003697	109068.75	16094973.85	4011.85	8023.71	7.3566
108	0.00355	.000000238	20617.35	802279.30	895.70	1791.40	8.6888
109	0.00932	.000001318	54125.21	4837992.63	2199.54	4399.09	8.1276
110	0.02241	.000001582	130161.35	15010431.88	3874.33	7748.66	5.9531
111	0.03050	.000000325	177212.52	22222167.00	4714.04	9428.08	5.3202
201	0.00052	.000000006	3043.74	20098.57	141.77	283.54	9.3155
202	0.13919	.000027084	808627.42	506320208.27	22501.56	45003.12	5.5654
203	0.02382	.000000085	138374.11	13305056.38	3647.61	7295.22	5.2721
204	0.00327	.000000130	18978.00	525862.13	725.16	1450.33	7.6422
205	0.00631	.000002869	36663.74	7084683.63	2661.71	5323.41	14.5196
301	0.03508	.000003186	203806.55	35311237.29	5942.33	11884.65	5.8313
302	0.00554	.000000412	32192.91	1596141.07	1263.38	2526.77	7.8488
303	0.00388	.000003022	22545.05	6839336.70	2615.21	5230.43	23.1999
401	0.14711	.000006171	854621.30	513829647.62	22667.81	45335.62	5.3048
402	0.01161	.000000250	67430.90	3652386.70	1911.12	3822.24	5.6684
403	0.00933	.000000336	54228.00	2736150.50	1654.13	3308.26	6.1007
404	0.00148	.000000030	8618.60	115327.66	339.60	679.20	7.8806
405	0.00439	.000000033	25481.99	515311.64	717.85	1435.70	5.6342
407	0.00349	.000000001	20246.22	282439.18	531.45	1062.90	5.2499
501	0.15645	.000012900	908874.66	593856133.09	24369.16	48738.33	5.3625
502	0.01517	.000000262	88153.71	5887944.63	2426.51	4853.02	5.5052
503	0.02347	.000000010	136330.27	12759389.87	3572.03	7144.06	5.2403
504	0.06834	.000004056	396988.04	116725272.43	10803.95	21607.89	5.4430
601	0.05833	.000002980	338829.88	85085111.51	9224.16	18448.32	5.4447
	=========		==========	=============	=========	=========	
	1.00000		5809336.41	2256812457.59	165976.97	331953.93	

Percent Error for Total Generated is 5.2%

APPENDIX C
Summary of Pollution Prevention Initiatives (by Stream)

POLLUTION PREVENTION ACTIVITIES: API Separator Sludge

EQUIPMENT/TECHNOLOGY MODIFICATIONS
Install segregated sewer system
Install zero sample valves at all units
Install new feed equipment to filter press

PROCEDURE MODIFICATIONS
Used gravity thickening which eliminated lime additives
Stopped use of filter press; reduced filter media
Use safe-t-cap covers during hot work to reduce dust
Segregated handling of biosludge, DAF float & API separator sludge

Initiate leak detection along pipes

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS
Replace chromates in cooling towers

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS
Improved cleaning, sweeping, housekeeping to reduce solids entering wastewater system
Paving process area to reduce dust
Regrade tank farms & reline sewers to reduce solids entering wastewater system
Personnel training
Begin "dry" cleaning of process areas

IN-PROCESS RECYCLE
IN REFINING PROCESS UNITS
Coker modified to accept API separator sludge
Sludge stream sent to flash zone of distillation column for thermal decomposition; oil recovered, water cycled to wastewater system & solids to asphalt
Recycle lab samples to oil recovery system

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION
Centrifuge
Thermal drying to reduce volume by 1/4
Shaker & filter press to dewater & recover oil
Filter press prior to incineration
Deoiling in pressure filter

OTHER RECYCLE

OUT-OF PROCESS RECYCLE
REUSE/RECLAMATION
Reuse as kiln fuel after additional drying of wet centrifuge cake or blending of oil into cake from filter press

POLLUTION PREVENTION ACTIVITIES: DAF Float

EQUIPMENT/TECHNOLOGY MODIFICATIONS
Install new feed equipment to filter press

PROCEDURE MODIFICATIONS
Reduced amount of biological sludge mixed with DAF; this reduced quantity going to coker
More effective decanting & polymerization
Use of safe-t-caps during hot work

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS
Improved cleaning, sweeping, housekeeping to reduce solids entering wastewater system
Paving areas to reduce dust
Education program to emphasize keeping solids out of sewer systems

IN-PROCESS RECYCLE
IN REFINING PROCESS UNITS
DAF float & sludge sent to coker
DAF float sent to crude unit
Coker injection
Dewatered oily material recycled through crude unit
Route DAF & IAF float for reprocessing in recovered oil system
Filter cake reslurried to coker

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION
Install thermal dryer(s) to maximize dewatering
Centrifuge/drier combination reduced volume by 75%
Use thermal auger
Low temperature drier used to further dewater sludge

OTHER RECYCLE

OUT-OF PROCESS RECYCLE
REUSE/RECLAMATION
Reuse as kiln fuel after additional drying of wet centrifuge cake or blending of oil into cake from filter press

POLLUTION PREVENTION ACTIVITIES: Slop Oil Emulsion Solids

EQUIPMENT/TECHNOLOGY MODIFICATIONS
- Install new feed equipment to filter press

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS
- Improved cleaning, sweeping, housekeeping to reduce solids entering wastewater system
- Paving areas to reduce dust
- Regularly scheduled street sweeping

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS
- Recycle to coker
- Oil recovered from MOSC unit returned to refining process
- Delayed coking of emulsion

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION
- Use low temperature dryer to further dewater sludge
- Use shaker &/or centrifuge and filter press

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION
- Recycled as fuel for industrial furnaces
- Reuse as kiln fuel after blending oil into cake from filter press

OTHER

POLLUTION PREVENTION ACTIVITIES: Leaded Tank Bottoms

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

Lead phase-out in gasoline; cease blending leaded fuels

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

Dewater tank bottoms

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

OTHER

POLLUTION PREVENTION ACTIVITIES: Pond Sediments

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

Redirected all water into sewers except rainwater runoff

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

Coker injection

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

OTHER

POLLUTION PREVENTION ACTIVITIES: Non-leaded Tank Bottoms

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

Liquified using "AKJ" process; recycle to reduced crude conversion unit
Reprocessed in coking unit

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

Centrifuge
Deoiled, dewatered
Deoil with pressure filter press

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

OTHER

POLLUTION PREVENTION ACTIVITIES: Residual Oils/Spent Solvents

EQUIPMENT/TECHNOLOGY MODIFICATIONS
Installed zero sample valves at all units

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS
Use of solvents other than TCE

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS
Began "dry-cleaning" process areas

IN-PROCESS RECYCLE
IN REFINING PROCESS UNITS
Recycle lab & crude unit samples to recovered oil system
Recycle to crude unit

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE
REUSE/RECLAMATION
Solvents as fuel for cement kiln
Waste oil/spent solvent to reclaimer
Spent MEK solvent recycled
Oily waste to boiler

OTHER

POLLUTION PREVENTION ACTIVITIES: Other Oily sludges/Organic Residuals

EQUIPMENT/TECHNOLOGY MODIFICATIONS

Modified equipment for TEG service

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

Increased review of inventory to avoid accumulation of chemicals

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

Reprocessed in coker

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

Dewatering

Sludge deoiling in filter press

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

OTHER

POLLUTION POLLUTION PREVENTION ACTIVITIES: F037 Primary Sludge

EQUIPMENT/TECHNOLOGY MODIFICATIONS
- Replace earthen ditches with hard piping
- Mixer placed on primary wastewater tank

PROCEDURE MODIFICATIONS
- Discontinued use of equalization basin
- Process water segregated from storm water

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS
- Process areas paved with new curbs

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS
- Reprocessed at coker

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION
- Dewatered and dried
- Sludge deoiled in pressure filter press

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

OTHER

POLLUTION PREVENTION ACTIVITIES: F038 Primary Sludge

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

To coker
Inititated delayed coking

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

OTHER

POLLUTION PREVENTION ACTIVITIES: Heat Exchanger Bundle Cleaning Sludge

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

<u>IN-PROCESS RECYCLE</u>

IN REFINING PROCESS UNITS

Coker

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

Recover oil & dewater by filter pressing/centrifugation

OTHER RECYCLE

<u>OUT-OF PROCESS RECYCLE</u>

REUSE/RECLAMATION

OTHER

POLLUTION PREVENTION ACTIVITIES: Contaminated Soils/Solids

EQUIPMENT/TECHNOLOGY MODIFICATIONS
Installed above ground tank water draw system

PROCEDURE MODIFICATIONS
Reduced disposal of sand blast grit by using recyclable steel grit with containment procedure

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS
Personnel training to increase awareness of soil contamination, spills
Use computerized gauging system for inventories
Provide containment for equipment subject to spills

IN-PROCESS RECYCLE
IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE
REUSE/RECLAMATION
Sent to cement kiln

OTHER

POLLUTION PREVENTION ACTIVITIES: Residual Coke/Carbon/Charcoal

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

Sent off-site for regeneration of carbon

OTHER

POLLUTION PREVENTION ACTIVITIES: Residual Sulfur

EQUIPMENT/TECHNOLOGY MODIFICATIONS
Modification of sulfur recovery unit

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS
Tighter process controls

IN-PROCESS RECYCLE
IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE
REUSE/RECLAMATION

OTHER

POLLUTION PREVENTION ACTIVITIES: Other Contaminated Soils NOS

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

- Extended cycle time of unit, reduced treatment clay generation
- Established better leak containment procedures

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

- Improved housekeeping

IN-PROCESS RECYCLE
IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE
REUSE/RECLAMATION

- Trial recycling of alumina catalyst w/ manufacturer
- Jet filter clay to cement kiln (feed)

OTHER

POLLUTION PREVENTION ACTIVITIES: FCCU Catalyst

EQUIPMENT/TECHNOLOGY MODIFICATIONS
- Redesign of catalytic unit cyclones for catalyst distribution
- Modified cyclones to increase outlet tube diameter

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS
- Reused at another refinery

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION
- Used as feed for kiln
- Regenerated by demetallization process
- Recycle to steel industry

OTHER

POLLUTION PREVENTION ACTIVITIES: Hydroprocessing Catalyst

EQUIPMENT/TECHNOLOGY MODIFICATIONS	**IN-PROCESS RECYCLE** **IN REFINING PROCESS UNITS** Regeneration for reuse in process
PROCEDURE MODIFICATIONS	**RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION**
	OTHER RECYCLE
REFORMULATION/REDESIGN OF PRODUCTS	**OUT-OF PROCESS RECYCLE** **REUSE/RECLAMATION** Sulfurgard catalyst shipped to metals reclamation facility Hydroprocessing catalyst to reclamation Precious metals recovery
SUBSTITUTION OF RAW MATERIALS	
IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS	**OTHER**

POLLUTION PREVENTION ACTIVITIES: Other Spent Catalysts

EQUIPMENT/TECHNOLOGY MODIFICATIONS

Install HF alkylation unit to replace catalytic polymerization unit

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

Non-hazardous sulfur plant alumina to cement manufacturer for feed

Polyblend sold for reuse as fertilizer blend

Reclaimed

OTHER

POLLUTION PREVENTION ACTIVITIES: Biomass

EQUIPMENT/TECHNOLOGY MODIFICATIONS
Install steam dryer

PROCEDURE MODIFICATIONS
Dewater by chemical addition
Stopped use of impoundment

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS
Increase upstream sewer surveillance
Better housekeeping to allow less oil to sewer

IN-PROCESS RECYCLE
IN REFINING PROCESS UNITS
Biomass pumped to reduced crude conversion unit for injection into riser

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION
Filter press sludge prior to incineration

OTHER RECYCLE
Recycled to re-seed refinery's land biotreatment unit

OUT-OF PROCESS RECYCLE
REUSE/RECLAMATION

OTHER

POLLUTION PREVENTION ACTIVITIES: Oil Contaminated Water not Wastewater

EQUIPMENT/TECHNOLOGY MODIFICATIONS

Modification of equipment (& operating procedures) reduced amount of water carried over with gasoline to storage tanks

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

OTHER

POLLUTION PREVENTION ACTIVITIES: High pH/low pH Waters

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

Cut use of water by 1% per day

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

OTHER

POLLUTION PREVENTION ACTIVITIES: Other Aqueous Waste NOS

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE
IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE
REUSE/RECLAMATION
Sulfolane recovered from wastewater; residuals treated

OTHER

POLLUTION PREVENTION ACTIVITIES: Spent Caustics

EQUIPMENT/TECHNOLOGY MODIFICATIONS
Installed caustic neutralizer

PROCEDURE MODIFICATIONS
Improved pH control, separation & recycle systems
Extend changeout cycle, due to planned shutdown of process unit

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS
Recycle slightly spent prewash caustics to other treaters
Intra-company reuse

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE
Internal recycle to fresh caustics tank

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION
Sold sulfide spend caustic to paper mill
Sold cresylic spent caustic to chemical manufacturer
Reuse spent caustic at bio-pond for pH control

OTHER

POLLUTION PREVENTION ACTIVITIES: Residual Amines

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

Formed task force to track losses & increase monitoring

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

Sold MDEA back to manufacturer
Regeneration
Initiated use of amine waste in fuel program

OTHER

POLLUTION PREVENTION ACTIVITIES: Other Inorganic Residuals NOS

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

<u>IN-PROCESS RECYCLE</u>

IN REFINING PROCESS UNITS

Recycle to coker

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

SDU

OTHER RECYCLE

<u>OUT-OF PROCESS RECYCLE</u>

REUSE/RECLAMATION

Sold off site for neutralization of acid ponds

Raw material for cement kiln

OTHER

POLLUTION PREVENTION ACTIVITIES: Other Residuals NOS

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS
- Initiated recycle of white office paper & cardboard
- Buy chemicals in bulk containers which reduces number of empty drums

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS
- Replacement of asbestos insulation
- Removal of PCB oils from electrical equipment

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS
- Waste paint to fuel blenders

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION
- Establish recycling for metal & wood
- Batteries sent back to distributor for reuse

OTHER

POLLUTION PREVENTION ACTIVITIES:

EQUIPMENT/TECHNOLOGY MODIFICATIONS

PROCEDURE MODIFICATIONS

REFORMULATION/REDESIGN OF PRODUCTS

SUBSTITUTION OF RAW MATERIALS

IMPROVED HOUSEKEEPING; TRAINING OF PERSONNEL OR INVENTORY CONTROLS

IN-PROCESS RECYCLE

IN REFINING PROCESS UNITS

RECOVERING OIL BY FILTER PRESSING/ CENTRIFUGATION

OTHER RECYCLE

OUT-OF PROCESS RECYCLE

REUSE/RECLAMATION

OTHER

APPENDIX D
SAS Data Tables

API REFINERY RESIDUALS SURVEY
1991

Estimated Residual Quantities Recycled and Percent Of Total Amount Managed
By Stream

Residual Stream	Quantity Recycled (Tons)	Percent Recycled
API Separator Sludge (K051)	61,641	28.80
Dissolved Air Flotation Float (K048)	140,343	34.27
Slop Oil Emulsion Solids (K049)	80,924	50.72
Leaded Tank Bottoms (K052)	111	17.08
Pond Sediments	3,223	0.85
Nonleaded Tank Bottoms	18,108	16.38
Residual Oils/Spent Solvents	20,353	98.75
Other Oily Sludges & Organic Residuals	6,955	12.82
Primary Sludge (F037)	1,128	0.85
Primary Sludge (F038)	7,157	3.98
Heat Exchanger Bundle Cleaning Sludge	47	1.62
Contaminated Soil/Solids	26,362	3.36
Residual Coke/Carbon/Charcoal	120,921	87.40
Residual Sulfur	224	1.18
Other Contaminated Soils NOS	2,835	7.72
Fluid Cracking Catalyst or Equivalent	56,139	27.55
Hydroprocessing Catalysts	31,017	94.89
Other Spent Catalysts NOS	7,223	31.13
Biomass	147,062	17.05
Oil Contaminated Water NOT Wastewater	6,223	9.23
High pH/Low pH Waters	0	0
Spent Sulfite Solution	8,619	99.99
Spent Stretford Solution	1,339	5.31
TSD Leachate (F039)	1,416	6.99
Spent Caustics	646,363	71.18
Spent Acids	84,041	95.34
Residual Amines	1,015	0.74
Other Inorganic Residuals NOS	45,997	11.69
Other Residuals NOS	62,809	18.51
	==========	
	1,589,595	

API REFINERY RESIDUALS SURVEY
1991

Estimated Residual Quantity Handled by Recycle Techniques for Each Residual Stream
(wet tons)

Residual Stream	Coker	Crude Unit	Desalter	Catalytic Cracker	Other In-Process Recycle	Cement Kiln-Out of Process
API Separator Sludge (K051)	31,201	10,992	0	148	0	3,400
Dissolved Air Flotation Float (K048)	55,516	71,866	0	0	9	43
Slop Oil Emulsion Solids (K049)	17,816	14,396	0	28,396	0	9
Leaded Tank Bottoms (K052)	0	0	0	0	0	3
Pond Sediments	1,741	11	0	0	0	0
Nonleaded Tank Bottoms	829	14,873	0	0	0	0
Residual Oils/Spent Solvents	20	14,921	0	4,321	11	0
Other Oily Sludges & Organic Residuals	49	45	494	0	1,669	0
Primary Sludge (F037)	49	681	0	0	0	0
Primary Sludge (F038)	1,284	4,255	0	0	0	0
Heat Exchanger Bundle Cleaning Sludge	7	5	0	0	0	15
Contaminated Soil/Solids	0	0	0	0	0	5,720
Residual Coke/Carbon/Charcoal	0	0	0	0	0	0
Residual Sulfur	0	0	0	0	0	0
Other Contaminated Soils NOS	297	2,044	0	0	0	230
Fluid Cracking Catalyst or Equivalent	0	2,334	0	3,807	0	33,573
Hydroprocessing Catalysts	0	0	0	0	0	0
Other Spent Catalysts NOS	0	0	0	136	21	0
Biomass	66,610	79,335	0	0	0	0
Oil Contaminated Water NOT Wastewater	4,069	734	0	0	0	0
High pH/Low pH Waters	0	0	0	0	0	0
Spent Sulfite Solution	0	0	0	0	0	0
Spent Stretford Solution	0	0	0	0	0	0
TSD Leachate (F039)	0	0	0	0	0	0
Spent Caustics	0	267	0	0	3,418	0
Spent Acids	0	0	0	0	4,186	0
Residual Amines	256	0	0	0	0	0
Other Inorganic Residuals NOS	842	8	0	0	13,296	8,433
Other Residuals NOS	0	40	0	0	0	23
	========	========	========	=========	==========	==========
	180,586	216,807	494	36,808	22,610	51,449

Continued on Next Page

API REFINERY RESIDUALS SURVEY
1991

Estimated Residual Quantity Handled by Recycle Techniques for Each Residual Stream (Continued)
(wet tons)

Residual Stream	Other Out-of-Process	Cement Kiln-Industrial Fuel	Other Industrial Fuel	Reclamation	Regeneration	Other
API Separator Sludge (K051)	0	15,681	0	219	0	0
Dissolved Air Flotation Float (K048)	0	11,666	0	1,243	0	0
Slop Oil Emulsion Solids (K049)	0	19,136	1,079	92	0	0
Leaded Tank Bottoms (K052)	0	0	0	0	0	108
Pond Sediments	0	21	0	1,450	0	0
Nonleaded Tank Bottoms	0	1,391	0	0	0	1,015
Residual Oils/Spent Solvents	0	535	52	417	67	9
Other Oily Sludges & Organic Residuals	8	112	4,506	72	0	0
Primary Sludge (F037)	398	0	0	0	0	0
Primary Sludge (F038)	0	0	0	1,618	0	0
Heat Exchanger Bundle Cleaning Sludge	0	4	0	0	0	16
Contaminated Soil/Solids	959	0	0	0	0	19,683
Residual Coke/Carbon/Charcoal	0	15	17,563	99,889	421	3,033
Residual Sulfur	200	0	0	0	0	24
Other Contaminated Soils NOS	0	24	0	20	0	220
Fluid Cracking Catalyst or Equivalent	2,488	702	0	3,691	2,626	6,918
Hydroprocessing Catalysts	0	0	0	27,322	3,281	414
Other Spent Catalysts NOS	804	0	0	5,288	379	595
Biomass	0	0	0	1,117	0	0
Oil Contaminated Water NOT Wastewater	0	0	0	1,420	0	0
High pH/Low pH Waters	0	0	0	0	0	0
Spent Sulfite Solution	0	0	0	7,608	0	1,011
Spent Stretford Solution	0	0	0	1,339	0	0
TSD Leachate (F039)	0	0	0	0	0	1,416
Spent Caustics	19,728	0	0	204,681	281,545	136,724
Spent Acids	53	0	0	0	79,802	0
Residual Amines	51	0	251	139	310	8
Other Inorganic Residuals NOS	8,603	1	0	1,430	0	13,384
Other Residuals NOS	0	4,830	1	44,636	0	13,279
	==============	===============	==========	===========	============	========
	33,292	54,118	23,452	403,691	368,431	197,857

API REFINERY RESIDUALS SURVEY
1991

Respondent Frequencies For Recycle Techniques For Each Residual Stream

Residual Stream	Coker	Crude Unit	Desalter	Catalytic Cracker	Other In-Process Recycle	Cement Kiln-Out of Process
API Separator Sludge (K051)	18	24	0	1	0	2
Dissolved Air Flotation Float (K048)	15	14	0	0	1	1
Slop Oil Emulsion Solids (K049)	6	9	0	2	0	1
Leaded Tank Bottoms (K052)	0	0	0	0	0	1
Pond Sediments	1	1	0	0	0	0
Nonleaded Tank Bottoms	4	8	0	0	0	0
Residual Oils/Spent Solvents	2	6	0	1	1	0
Other Oily Sludges & Organic Residuals	2	2	1	0	1	0
Primary Sludge (F037)	2	4	0	0	0	0
Primary Sludge (F038)	3	5	0	0	0	0
Heat Exchanger Bundle Cleaning Sludge	2	1	0	0	0	2
Contaminated Soil/Solids	0	0	0	0	0	3
Residual Coke/Carbon/Charcoal	0	0	0	0	0	0
Residual Sulfur	0	0	0	0	0	0
Other Contaminated Soils NOS	1	1	0	0	0	1
Fluid Cracking Catalyst or Equivalent	0	1	0	7	0	12
Hydroprocessing Catalysts	0	0	0	0	0	0
Other Spent Catalysts NOS	0	0	0	1	1	0
Biomass	2	3	0	0	0	0
Oil Contaminated Water NOT Wastewater	2	2	0	0	0	0
High pH/Low pH Waters	0	0	0	0	0	0
Spent Sulfite Solution	0	0	0	0	0	0
Spent Stretford Solution	0	0	0	0	0	0
TSD Leachate (F039)	0	0	0	0	0	0
Spent Caustics	0	1	0	0	1	0
Spent Acids	0	0	0	0	1	0
Residual Amines	2	0	0	0	0	0
Other Inorganic Residuals NOS	2	2	0	0	1	1
Other Residuals NOS	0	1	0	0	0	1
	=====	=====	========	=========	==========	==========
	64	85	1	12	7	25

Continued on Next Page

API REFINERY RESIDUALS SURVEY
1991

Respondent Frequencies for Recycle Techniques for Each Residual Stream (Continued)

Residual Stream	Other Out of Process	Cement Kiln-Industrial Fuel	Other Industrial Fuel	Reclamation	Regeneration	Other
API Separator Sludge (K051)	0	17	0	2	0	0
Dissolved Air Flotation Float (K048)	0	11	0	2	0	0
Slop Oil Emulsion Solids (K049)	0	15	1	1	0	0
Leaded Tank Bottoms (K052)	0	0	0	0	0	1
Pond Sediments	0	1	0	2	0	0
Nonleaded Tank Bottoms	0	1	0	0	0	1
Residual Oils/Spent Solvents	0	13	1	34	8	2
Other Oily Sludges & Organic Residuals	1	3	3	3	0	0
Primary Sludge (F037)	1	0	0	0	0	0
Primary Sludge (F038)	0	0	0	1	0	0
Heat Exchanger Bundle Cleaning Sludge	0	2	0	0	0	1
Contaminated Soil/Solids	2	0	0	0	0	4
Residual Coke/Carbon/Charcoal	0	1	2	1	6	1
Residual Sulfur	1	0	0	0	0	2
Other Contaminated Soils NOS	0	1	0	2	0	1
Fluid Cracking Catalyst or Equivalent	3	1	0	6	2	9
Hydroprocessing Catalysts	0	0	0	44	14	2
Other Spent Catalysts NOS	2	0	0	36	4	2
Biomass	0	0	0	1	0	0
Oil Contaminated Water NOT Wastewater	0	0	0	2	0	0
High pH/Low pH Waters	0	0	0	0	0	0
Spent Sulfite Solution	0	0	0	1	0	1
Spent Stretford Solution	0	0	0	1	0	0
TSD Leachate (F039)	0	0	0	0	0	1
Spent Caustics	9	0	0	19	4	16
Spent Acids	1	0	0	0	2	0
Residual Amines	1	0	2	2	1	1
Other Inorganic Residuals NOS	2	1	0	2	0	4
Other Residuals NOS	0	3	1	22	0	9
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	23	70	10	184	41	58

API ANNUAL REFINING SURVEY
1991

Percent Recycled On-Site and Off-Site

Waste Stream	Recycled Tons	Percent Recycled On-Site	Percent Recycled Off-Site
API Separator Sludge (K051)	61,641	67	33
Dissolved Air Flotation Float (K048)	140,343	92	8
Slop Oil Emulsion Solids (K049)	80,925	75	25
Leaded Tank Bottoms (K052)	111	98	2
Pond Sediments	3,223	45	55
Nonleaded Tank Bottoms	18,108	92	8
Residual Oils/Spent Solvents	20,353	95	5
Other Oily Sludges & Organic Residuals	6,955	8	92
Primary Sludge (F037)	1,128	65	35
Primary Sludge (F038)	7,157	100	0
Heat Exchanger Bundle Cleaning Sludge	47	60	40
Contaminated Soil/Solids	26,362	25	75
Residual Coke/Carbon/Charcoal	120,921	3	97
Residual Sulfur	224	3	97
Other Contaminated Soils NOS	2,835	82	18
Fluid Cracking Catalyst or Equivalent	56,140	4	96
Hydroprocessing Catalysts	31,017	1	99
Other Spent Catalysts NOS	7,224	7	93
Biomass	147,062	100	0
Oil Contaminated Water NOT Wastewater	6,224	100	0
High pH/Low pH Waters	0	0	0
Spent Sulfite Solution	8,619	0	100
Spent Stretford Solution	1,339	0	100
TSD Leachate (F039)	1,416	100	0
Spent Caustics	646,363	47	53
Spent Acids	84,042	0	100
Residual Amines	1,015	57	43
Other Inorganic Residuals NOS	45,998	3	97
Other Residuals NOS	62,809	1	99
	==========		
	1,589,601		

API REFINERY RESIDUALS SURVEY
1991

Estimated Residual Quantities Treated and Percent Of Total Amount Managed
By Stream

Residual Stream	Quantity Treated (Tons)	Percent Treated
API Separator Sludge (K051)	147,092	68.72
Dissolved Air Flotation Float (K048)	267,287	65.26
Slop Oil Emulsion Solids (K049)	78,225	49.03
Leaded Tank Bottoms (K052)	272	41.85
Pond Sediments	29,493	7.75
Nonleaded Tank Bottoms	6,001	5.43
Residual Oils/Spent Solvents	35	0.17
Other Oily Sludges & Organic Residuals	1,527	2.81
Primary Sludge (F037)	59,347	44.74
Primary Sludge (F038)	139,247	77.39
Heat Exchanger Bundle Cleaning Sludge	1,340	46.18
Contaminated Soil/Solids	4,523	0.58
Residual Coke/Carbon/Charcoal	1,086	0.78
Residual Sulfur	0	0
Other Contaminated Soils NOS	1,319	3.59
Fluid Cracking Catalyst or Equivalent	2,085	1.02
Hydroprocessing Catalysts	0	0
Other Spent Catalysts NOS	2,216	9.55
Biomass	448,595	52.02
Oil Contaminated Water NOT Wastewater	59,139	87.70
High pH/Low pH Waters	7	0.01
Spent Sulfite Solution	0	0
Spent Stretford Solution	19,294	76.58
TSD Leachate (F039)	804	3.97
Spent Caustics	228,872	25.20
Spent Acids	3,711	4.21
Residual Amines	133,589	97.63
Other Inorganic Residuals NOS	69,840	17.75
Other Residuals NOS	2,194	0.65
	==========	
	1,707,140	

API REFINERY RESIDUALS SURVEY
1991

Estimated Residual Quantity Handled By Treatment Techniques For Each Residual Stream
(wet tons)

Residual Stream	Weathering	Chemical	Heat	Impoundment	Physical	Waste water Treatment	Incineration	Stabilization and/or Fixation	Other
API Separator Sludge (K051)	0	24	3,695	0	1,515	112,760	29,098	0	0
Dissolved Air Flotation Float (K048)	0	0	1,302	0	83	208,287	57,615	0	0
Slop Oil Emulsion Solids (K049)	0	0	975	0	0	57,782	19,468	0	0
Leaded Tank Bottoms (K052)	0	0	4	0	0	0	268	0	0
Pond Sediments	0	0	0	0	0	9,558	19,254	0	681
Nonleaded Tank Bottoms	0	0	11	0	0	4,863	92	1,035	0
Residual Oils/Spent Solvents	0	0	0	0	0	0	35	0	0
Other Oily Sludges & Organic Residuals	0	0	267	0	0	1,207	53	0	0
Primary Sludge (F037)	0	0	0	0	0	58,459	888	0	0
Primary Sludge (F038)	0	0	0	0	0	139,166	81	0	0
Heat Exchanger Bundle Cleaning Sludge	0	0	0	0	0	92	1,248	0	0
Contaminated Soil/Solids	334	0	0	0	0	0	3,578	611	0
Residual Coke/Carbon/Charcoal	0	0	983	0	0	0	80	23	0
Residual Sulfur	0	0	0	0	0	0	0	0	0
Other Contaminated Soils NOS	1	0	8	0	0	0	400	910	0
Fluid Cracking Catalyst or Equivalent	0	601	0	0	0	1,484	0	0	0
Hydroprocessing Catalysts	0	0	0	0	0	0	0	0	0
Other Spent Catalysts NOS	0	0	0	0	0	2,213	3	0	0
Biomass	0	0	0	0	0	354,490	81,504	0	12,601
Oil Contaminated Water NOT Wastewater	0	0	0	0	0	59,139	0	0	0
High pH/Low pH Waters	0	0	0	0	0	7	0	0	0
Spent Sulfite Solution	0	0	0	0	0	0	0	0	0
Spent Stretford Solution	0	0	0	1,144	0	18,150	0	0	0
TSD Leachate (F039)	0	0	0	0	0	804	0	0	0
Spent Caustics	0	37	0	0	0	228,835	0	0	0
Spent Acids	0	21	0	0	0	3,480	91	0	119
Residual Amines	0	0	0	71	0	133,367	151	0	0
Other Inorganic Residuals NOS	1	109	0	0	0	69,643	0	0	87
Other Residuals NOS	0	0	0	0	0	1,204	878	37	75
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	336	792	7,245	1,215	1,598	1464990	214,785	2,616	13,563

API REFINERY RESIDUALS SURVEY
1991

Respondent Frequencies For Treatment Techniques For Each Residual Stream

Residual Stream	Weathering	Chemical	Heat	Impoundment	Physical	Wastewater Treatment	Incineration	Stabilization and/or Fixation	Other
API Separator Sludge (K051)	0	1	4	0	2	30	49	0	0
Dissolved Air Flotation Float (K048)	0	0	3	0	2	19	24	0	0
Slop Oil Emulsion Solids (K049)	0	0	2	0	0	10	18	0	0
Leaded Tank Bottoms (K052)	0	0	1	0	0	0	15	0	0
Pond Sediments	0	0	0	0	0	5	1	0	1
Nonleaded Tank Bottoms	0	0	1	0	0	11	5	1	0
Residual Oils/Spent Solvents	0	0	0	0	0	0	11	0	0
Other Oily Sludges & Organic Residuals	0	0	1	0	0	3	8	0	0
Primary Sludge (F037)	0	0	0	0	0	13	5	0	0
Primary Sludge (F038)	0	0	0	0	0	7	1	0	0
Heat Exchanger Bundle Cleaning Sludge	0	0	0	0	0	5	25	0	0
Contaminated Soil/Solids	1	0	0	0	0	0	8	1	0
Residual Coke/Carbon/Charcoal	0	0	2	0	0	0	5	1	0
Residual Sulfur	0	0	0	0	0	0	0	0	0
Other Contaminated Soils NOS	1	0	1	0	0	0	7	1	0
Fluid Cracking Catalyst or Equivalent	0	1	0	0	0	1	0	0	0
Hydroprocessing Catalysts	0	0	0	0	0	0	0	0	0
Other Spent Catalysts NOS	0	0	0	0	0	1	2	0	0
Biomass	0	0	0	0	0	13	6	0	2
Oil Contaminated Water NOT Wastewater	0	0	0	0	0	4	0	0	0
High pH/Low pH Waters	0	0	0	0	0	1	0	0	0
Spent Sulfite Solution	0	0	0	0	0	0	0	0	0
Spent Stretford Solution	0	0	0	1	0	3	0	0	0
TSD Leachate (F039)	0	0	0	0	0	1	0	0	0
Spent Caustics	0	1	0	0	0	24	0	0	0
Spent Acids	0	1	0	0	0	7	1	0	2
Residual Amines	0	0	0	1	0	14	1	0	0
Other Inorganic Residuals NOS	1	1	0	0	0	15	0	0	2
Other Residuals NOS	0	0	0	0	0	6	31	2	2
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	3	5	15	2	4	193	223	6	9

API ANNUAL REFINING SURVEY
1991

Percent Treated On-Site and Off-Site

Waste Stream	Treated Tons	Percent Treated On-Site	Percent Treated Off-Site
API Separator Sludge (K051)	147,093	81	19
Dissolved Air Flotation Float (K048)	267,286	92	8
Slop Oil Emulsion Solids (K049)	78,224	75	25
Leaded Tank Bottoms (K052)	272	0	100
Pond Sediments	29,494	35	65
Nonleaded Tank Bottoms	6,001	97	3
Residual Oils/Spent Solvents	35	4	96
Other Oily Sludges & Organic Residuals	1,527	97	3
Primary Sludge (F037)	59,346	98	2
Primary Sludge (F038)	139,247	100	0
Heat Exchanger Bundle Cleaning Sludge	1,340	7	93
Contaminated Soil/Solids	4,523	21	79
Residual Coke/Carbon/Charcoal	1,085	92	8
Residual Sulfur	0	0	0
Other Contaminated Soils NOS	1,319	70	30
Fluid Cracking Catalyst or Equivalent	2,085	0	100
Hydroprocessing Catalysts	0	0	0
Other Spent Catalysts NOS	2,216	100	0
Biomass	448,595	61	39
Oil Contaminated Water NOT Wastewater	59,139	100	0
High pH/Low pH Waters	7	100	0
Spent Sulfite Solution	0	0	0
Spent Stretford Solution	19,294	82	18
TSD Leachate (F039)	804	100	0
Spent Caustics	228,872	82	18
Spent Acids	3,711	41	59
Residual Amines	133,588	100	0
Other Incrganic Residuals NOS	69,841	52	48
Other Residuals NOS	2,195	57	43
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	1,707,139		

API REFINERY RESIDUALS SURVEY
1991

Estimated Residual Quantities Land Treated and Percent Of Total Amount Managed
By Stream

Residual Stream	Quantity Land Treated (Tons)	Percent Land Treated
API Separator Sludge (K051)	0	0.00
Dissolved Air Flotation Float (K048)	4	0.00
Slop Oil Emulsion Solids (K049)	0	0.00
Leaded Tank Bottoms (K052)	0	0.00
Pond Sediments	10,692	2.81
Nonleaded Tank Bottoms	8,978	8.12
Residual Oils/Spent Solvents	111	0.54
Other Oily Sludges & Organic Residuals	8,660	15.96
Primary Sludge (F037)	27,136	20.46
Primary Sludge (F038)	0	0.00
Heat Exchanger Bundle Cleaning Sludge	0	0.00
Contaminated Soil/Solids	268,366	34.17
Residual Coke/Carbon/Charcoal	259	0.19
Residual Sulfur	0	0.00
Other Contaminated Soils NOS	1,824	4.97
Fluid Cracking Catalyst or Equivalent	20	0.01
Hydroprocessing Catalysts	0	0.00
Other Spent Catalysts NOS	1,149	4.95
Biomass	201,498	23.37
Oil Contaminated Water NOT Wastewater	1,223	1.81
High pH/Low pH Waters	23	0.04
Spent Sulfite Solution	0	0.00
Spent Stretford Solution	0	0.00
TSD Leachate (F039)	0	0.00
Spent Caustics	7	0.00
Spent Acids	0	0.00
Residual Amines	31	0.02
Other Inorganic Residuals NOS	8,243	2.10
Other Residuals NOS	41	0.01
	==========	
	538,265	

API REFINERY RESIDUALS SURVEY
1991

Respondent Frequencies For Land Treatment For Each Residual Stream

Residual Stream	Land Treatment
	12
Dissolved Air Flotation Float (K048)	1
Pond Sediments	4
Nonleaded Tank Bottoms	12
Residual Oils/Spent Solvents	2
Other Oily Sludges & Organic Residuals	8
Primary Sludge (F037)	12
Contaminated Soil/Solids	11
Residual Coke/Carbon/Charcoal	4
Other Contaminated Soils NOS	7
Fluid Cracking Catalyst or Equivalent	2
Other Spent Catalysts NOS	3
Biomass	11
Oil Contaminated Water NOT Wastewater	1
High pH/Low pH Waters	1
Spent Caustics	1
Residual Amines	3
Other Inorganic Residuals NOS	8
Other Residuals NOS	4
	=========
	107

API ANNUAL REFINING SURVEY
1991

Percent Land Treated On-Site and Off-Site

Waste Stream	Land Treated Tons	Percent Land Treated On-Site	Percent Land Treated Off-Site
API Separator Sludge (K051)	0	0	0
Dissolved Air Flotation Float (K048)	4	100	0
Slop Oil Emulsion Solids (K049)	0	0	0
Leaded Tank Bottoms (K052)	0	0	0
Pond Sediments	10,692	8	92
Nonleaded Tank Bottoms	8,978	100	0
Residual Oils/Spent Solvents	111	95	5
Other Oily Sludges & Organic Residuals	8,660	100	0
Primary Sludge (F037)	27,136	100	0
Primary Sludge (F038)	0	0	0
Heat Exchanger Bundle Cleaning Sludge	0	0	0
Contaminated Soil/Solids	268,366	100	0
Residual Coke/Carbon/Charcoal	259	100	0
Residual Sulfur	0	0	0
Other Contaminated Soils NOS	1,824	55	45
Fluid Cracking Catalyst or Equivalent	20	100	0
Hydroprocessing Catalysts	0	0	0
Other Spent Catalysts NOS	1,149	100	0
Biomass	201,498	98	2
Oil Contaminated Water NOT Wastewater	1,223	100	0
High pH/Low pH Waters	23	100	0
Spent Sulfite Solution	0	0	0
Spent Stretford Solution	0	0	0
TSD Leachate (F039)	0	0	0
Spent Caustics	7	100	0
Spent Acids	0	0	0
Residual Amines	31	57	43
Other Inorganic Residuals NOS	8,243	99	1
Other Residuals NOS	41	77	23
	==========		
	538,265		

API REFINERY RESIDUALS SURVEY
1991

Estimated Residual Quantities Disposed and Percent Of Total Amount Managed
By Stream

Waste Stream	Quantity Disposed (Tons)	Percent Disposed
API Separator Sludge (K051)	5,298	2.48
Dissolved Air Flotation Float (K048)	1,917	0.47
Slop Oil Emulsion Solids (K049)	387	0.24
Leaded Tank Bottoms (K052)	267	41.08
Pond Sediments	337,244	88.60
Nonleaded Tank Bottoms	77,450	70.07
Residual Oils/Spent Solvents	111	0.54
Other Oily Sludges & Organic Residuals	37,127	68.41
Primary Sludge (F037)	45,023	33.95
Primary Sludge (F038)	33,516	18.63
Heat Exchanger Bundle Cleaning Sludge	1,515	52.21
Contaminated Soil/Solids	486,167	61.90
Residual Coke/Carbon/Charcoal	16,093	11.63
Residual Sulfur	18,811	98.82
Other Contaminated Soils NOS	30,745	83.72
Fluid Cracking Catalyst or Equivalent	145,562	71.42
Hydroprocessing Catalysts	1,671	5.11
Other Spent Catalysts NOS	12,613	54.36
Biomass	65,164	7.56
Oil Contaminated Water NOT Wastewater	845	1.25
High pH/Low pH Waters	54,199	99.94
Spent Sulfite Solution	1	0.01
Spent Stretford Solution	4,562	18.11
TSD Leachate (F039)	18,026	89.03
Spent Caustics	32,813	3.61
Spent Acids	401	0.45
Residual Amines	2,202	1.61
Other Inorganic Residuals NOS	269,290	68.46
Other Residuals NOS	274,191	80.83
	==========	
	1,973,211	

API REFINERY RESIDUALS SURVEY
1991

Estimated Residual Quantity Handled by Disposal Techniques for Each Residual Stream
(wet tons)

Residual Stream	Disposal Impoundment	Landfill	Landspread	Injection	Other
API Separator Sludge (K051)	1	5,297	0	0	0
Dissolved Air Flotation Float (K048)	0	1,168	0	0	749
Slop Oil Emulsion Solids (K049)	0	387	0	0	0
Leaded Tank Bottoms (K052)	0	267	0	0	0
Pond Sediments	0	327,783	9,461	0	0
Nonleaded Tank Bottoms	0	74,773	2,658	0	19
Residual Oils/Spent Solvents	0	83	0	0	28
Other Oily Sludges & Organic Residuals	0	24,220	12,772	108	27
Primary Sludge (F037)	0	39,877	4,173	0	973
Primary Sludge (F038)	7,053	26,463	0	0	0
Heat Exchanger Bundle Cleaning Sludge	0	1,460	0	0	55
Contaminated Soil/Solids	0	479,782	6,385	0	0
Residual Coke/Carbon/Charcoal	0	16,093	0	0	0
Residual Sulfur	0	18,810	0	0	1
Other Contaminated Soils NOS	5	30,704	23	0	13
Fluid Cracking Catalyst or Equivalent	25,453	118,478	1,631	0	0
Hydroprocessing Catalysts	0	1,671	0	0	0
Other Spent Catalysts NOS	0	12,215	0	0	398
Biomass	1,602	40,997	22,565	0	0
Oil Contaminated Water NOT Wastewater	0	0	0	626	219
High pH/Low pH Waters	0	0	0	147	54,052
Spent Sulfite Solution	0	0	0	1	0
Spent Stretford Solution	4,562	0	0	0	0
TSD Leachate (F039)	18,026	0	0	0	0
Spent Caustics	0	75	0	31,575	1,163
Spent Acids	1	41	0	358	1
Residual Amines	264	470	0	1,468	0
Other Inorganic Residuals NOS	52,601	210,313	4,220	330	1,826
Other Residuals NOS	0	271,754	2,418	0	19
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	109,568	1,703,181	66,306	34,613	59,543

API REFINERY RESIDUALS SURVEY
1991

Respondent Frequencies for Disposal Techniques for Each Residual Stream

Residual Stream	Disposal Impoundment	Landfill	Landspread	Injection	Other
API Separator Sludge (K051)	1	12	0	0	0
Dissolved Air Flotation Float (K048)	0	5	0	0	2
Slop Oil Emulsion Solids (K049)	0	6	0	0	0
Leaded Tank Bottoms (K052)	0	5	0	0	0
Pond Sediments	0	19	1	0	0
Nonleaded Tank Bottoms	0	56	6	0	1
Residual Oils/Spent Solvents	0	2	0	0	2
Other Oily Sludges & Organic Residuals	0	23	1	2	1
Primary Sludge (F037)	0	43	2	0	2
Primary Sludge (F038)	2	8	0	0	0
Heat Exchanger Bundle Cleaning Sludge	0	13	0	0	2
Contaminated Soil/Solids	0	91	7	0	0
Residual Coke/Carbon/Charcoal	0	48	0	0	0
Residual Sulfur	0	41	0	0	1
Other Contaminated Soils NOS	1	65	1	0	1
Fluid Cracking Catalyst or Equivalent	4	55	3	0	0
Hydroprocessing Catalysts	0	16	0	0	0
Other Spent Catalysts NOS	0	52	0	0	1
Biomass	1	20	6	0	0
Oil Contaminated Water NOT Wastewater	0	0	0	1	1
High pH/Low pH Waters	0	0	0	1	2
Spent Sulfite Solution	0	0	0	1	0
Spent Stretford Solution	1	0	0	0	0
TSD Leachate (F039)	1	0	0	0	0
Spent Caustics	0	1	0	9	3
Spent Acids	1	3	0	1	1
Residual Amines	1	6	0	2	0
Other Inorganic Residuals NOS	6	46	6	1	1
Other Residuals NOS	0	105	2	0	1
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	19	741	35	18	22

API ANNUAL REFINING SURVEY
1991

Percent Disposed On-Site and Off-Site

Waste Stream	Disposed Tons	Percent Disposed On-Site	Percent Disposed Off-Site
API Separator Sludge (K051)	5,299	0	100
Dissolved Air Flotation Float (K048)	1,917	0	100
Slop Oil Emulsion Solids (K049)	387	0	100
Leaded Tank Bottoms (K052)	267	0	100
Pond Sediments	337,244	63	37
Nonleaded Tank Bottoms	77,451	9	91
Residual Oils/Spent Solvents	111	0	100
Other Oily Sludges & Organic Residuals	37,127	55	45
Primary Sludge (F037)	45,023	14	86
Primary Sludge (F038)	33,516	39	61
Heat Exchanger Bundle Cleaning Sludge	1,515	0	100
Contaminated Soil/Solids	486,167	13	87
Residual Coke/Carbon/Charcoal	16,093	38	62
Residual Sulfur	18,811	6	94
Other Contaminated Soils NOS	30,746	13	87
Fluid Cracking Catalyst or Equivalent	145,562	26	74
Hydroprocessing Catalysts	1,671	20	80
Other Spent Catalysts NOS	12,613	25	75
Biomass	65,164	43	57
Oil Contaminated Water NOT Wastewater	845	26	74
High pH/Low pH Waters	54,199	99	1
Spent Sulfite Solution	1	0	100
Spent Stretford Solution	4,562	0	100
TSD Leachate (F039)	18,026	100	0
Spent Caustics	32,812	55	45
Spent Acids	402	0	100
Residual Amines	2,203	78	22
Other Inorganic Residuals NOS	269,290	25	75
Other Residuals NOS	274,190	49	51
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	1,973,214		

API REFINERY RESIDUALS SURVEY
1991

Estimated Residual Quantities By Management Techniques
(wet tons)

Residual Stream	Total Managed	Recycled	Treated	Land Treated	Disposed
API Separator Sludge (K051)	214,031	61,641	147,092	0	5,298
Dissolved Air Flotation Float (K048)	409,551	140,343	267,287	4	1,917
Slop Oil Emulsion Solids (K049)	159,536	80,924	78,225	0	387
Leaded Tank Bottoms (K052)	650	111	272	0	267
Pond Sediments	380,652	3,223	29,493	10,692	337,244
Nonleaded Tank Bottoms	110,537	18,108	6,001	8,978	77,450
Residual Oils/Spent Solvents	20,610	20,353	35	111	111
Other Oily Sludges & Organic Residuals	54,269	6,955	1,527	8,660	37,127
Primary Sludge (F037)	132,634	1,128	59,347	27,136	45,023
Primary Sludge (F038)	179,920	7,157	139,247	0	33,516
Heat Exchanger Bundle Cleaning Sludge	2,902	47	1,340	0	1,515
Contaminated Soil/Solids	785,418	26,362	4,523	268,366	486,167
Residual Coke/Carbon/Charcoal	138,359	120,921	1,086	259	16,093
Residual Sulfur	19,035	224	0	0	18,811
Other Contaminated Soils NOS	36,723	2,835	1,319	1,824	30,745
Fluid Cracking Catalyst or Equivalent	203,806	56,139	2,085	20	145,562
Hydroprocessing Catalysts	32,688	31,017	0	0	1,671
Other Spent Catalysts NOS	23,201	7,223	2,216	1,149	12,613
Biomass	862,319	147,062	448,595	201,498	65,164
Oil Contaminated Water NOT Wastewater	67,430	6,223	59,139	1,223	845
High pH/Low pH Waters	54,229	0	7	23	54,199
Spent Sulfite Solution	8,620	8,619	0	0	1
Spent Stretford Solution	25,195	1,339	19,294	0	4,562
TSD Leachate (F039)	20,246	1,416	804	0	18,026
Spent Caustics	908,055	646,363	228,872	7	32,813
Spent Acids	88,153	84,041	3,711	0	401
Residual Amines	136,837	1,015	133,589	31	2,202
Other Inorganic Residuals NOS	393,370	45,997	69,840	8,243	269,290
Other Residuals NOS	339,235	62,809	2,194	41	274,191
	==========	==========	==========	==========	==========
	5,808,211	1,589,595	1,707,140	538,265	1,973,211

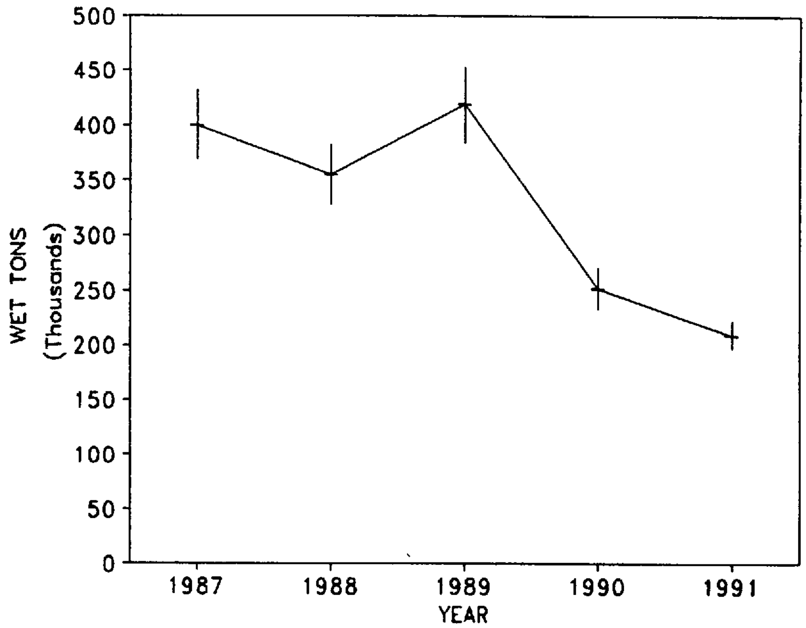
API REFINERY RESIDUALS SURVEY
1991

Percentages of Residual Quantities Recycled, Treated, Land Treated and Disposed
By Stream

Residual Stream	Percent Recycled	Percent Treated	Percent Land Treated	Percent Disposed
API Separator Sludge (K051)	29	69	0	2
Dissolved Air Flotation Float (K048)	34	65	0	0
Slop Oil Emulsion Solids (K049)	51	49	0	0
Leaded Tank Bottoms (K052)	17	42	0	41
Pond Sediments	1	8	3	89
Nonleaded Tank Bottoms	16	5	8	70
Residual Oils/Spent Solvents	99	0	1	1
Other Oily Sludges & Organic Residuals	13	3	16	68
Primary Sludge (F037)	1	45	20	34
Primary Sludge (F038)	4	77	0	19
Heat Exchanger Bundle Cleaning Sludge	2	46	0	52
Contaminated Soil/Solids	3	1	34	62
Residual Coke/Carbon/Charcoal	87	1	0	12
Residual Sulfur	1	0	0	99
Other Contaminated Soils NOS	8	4	5	84
Fluid Cracking Catalyst or Equivalent	28	1	0	71
Hydroprocessing Catalysts	95	0	0	5
Other Spent Catalysts NOS	31	10	5	54
Biomass	17	52	23	8
Oil Contaminated Water NOT Wastewater	9	88	2	1
High pH/Low pH Waters	0	0	0	100
Spent Sulfite Solution	100	0	0	0
Spent Stretford Solution	5	77	0	18
TSD Leachate (F039)	7	4	0	89
Spent Caustics	71	25	0	4
Spent Acids	95	4	0	0
Residual Amines	1	98	0	2
Other Inorganic Residuals NOS	12	18	2	68
Other Residuals NOS	19	1	0	81

APPENDIX E
Trend Data on Generation and Management Practices (by Stream)

API Separator Sludge



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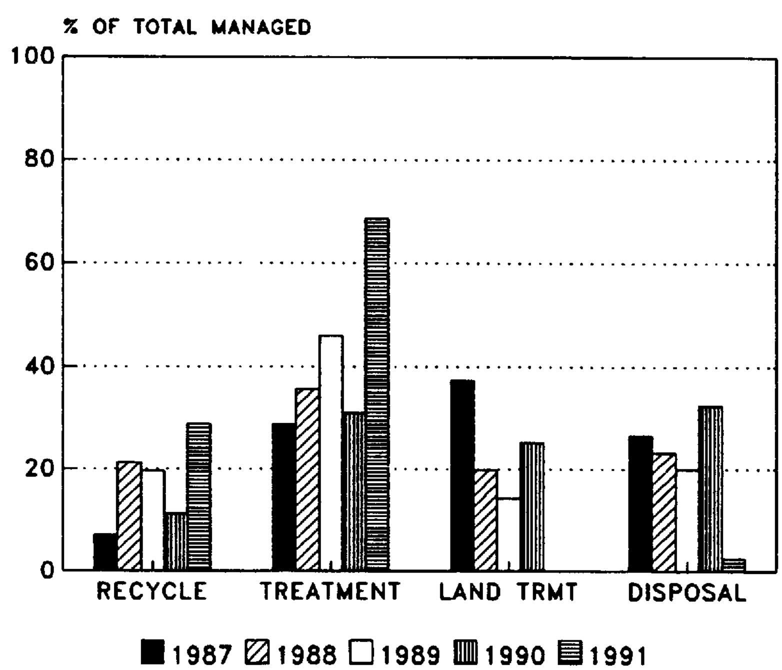
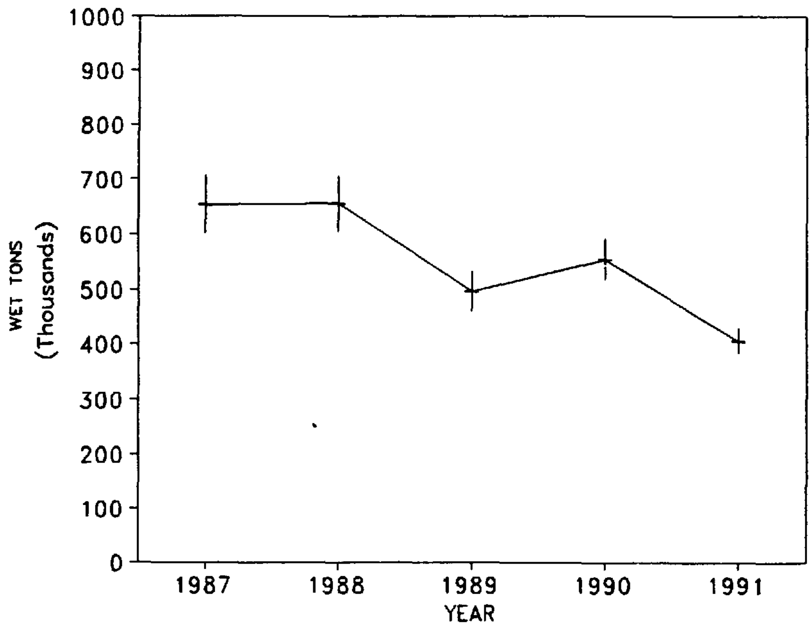


Management

Dissolved Air Flotation Float



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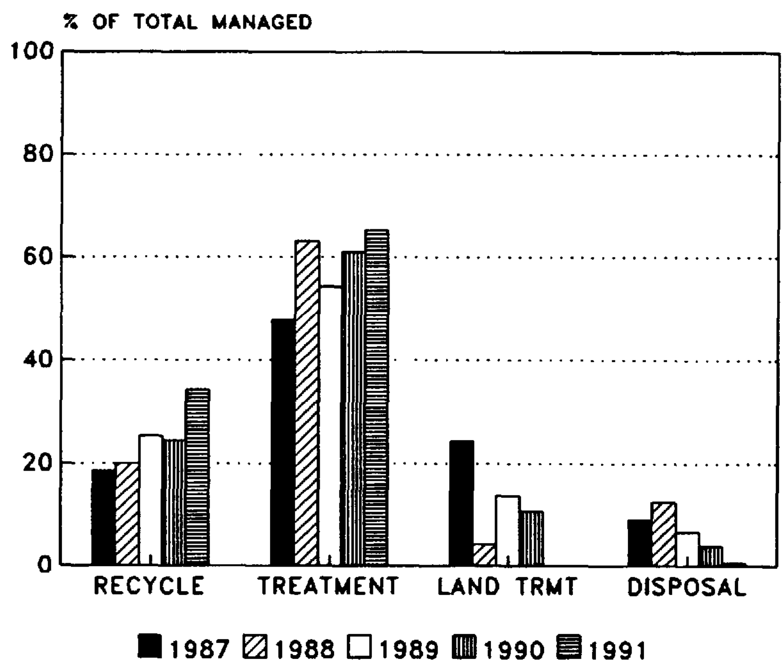
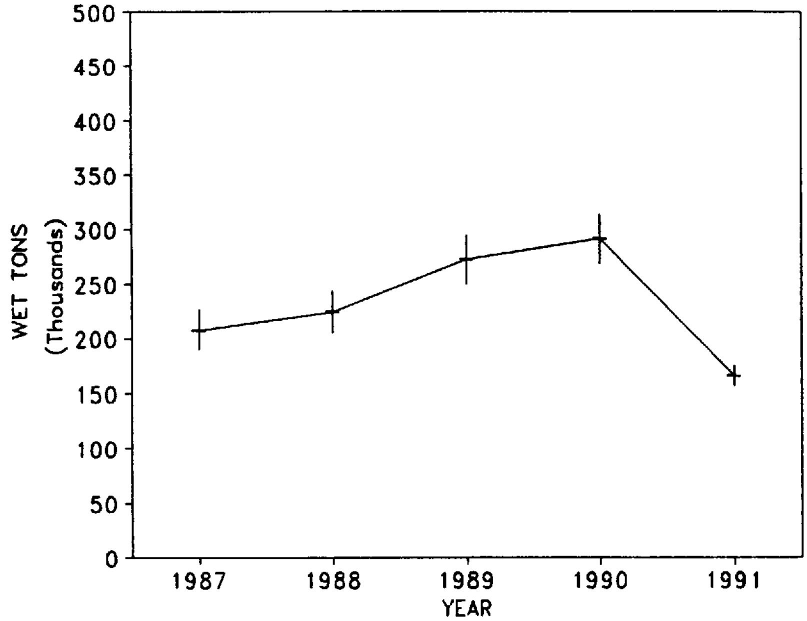


Management

Slop Oil Emulsion Solids



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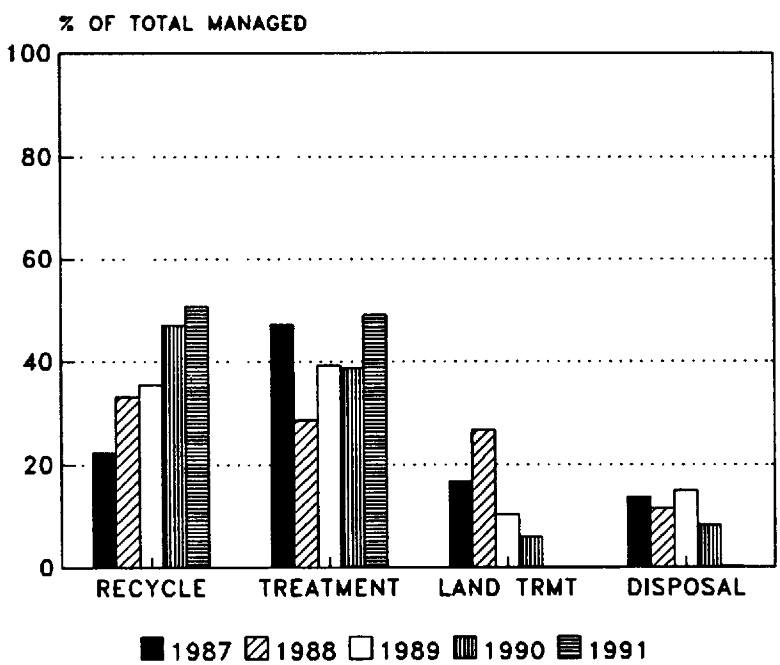
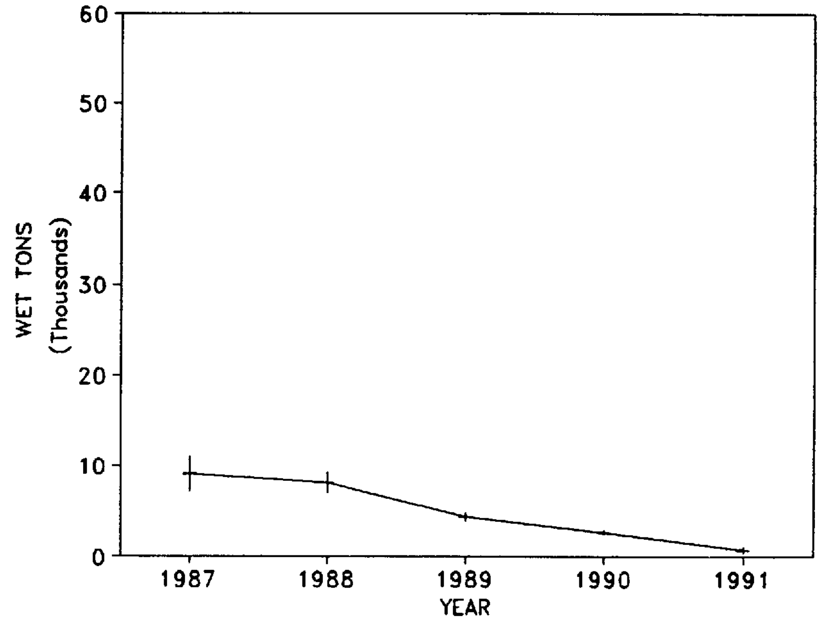


Management

Leaded Tank Bottoms



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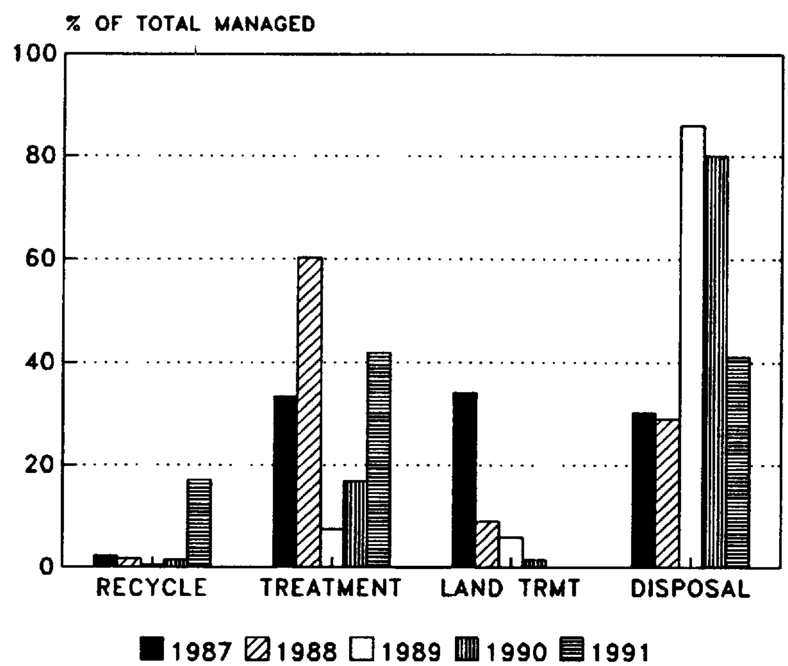
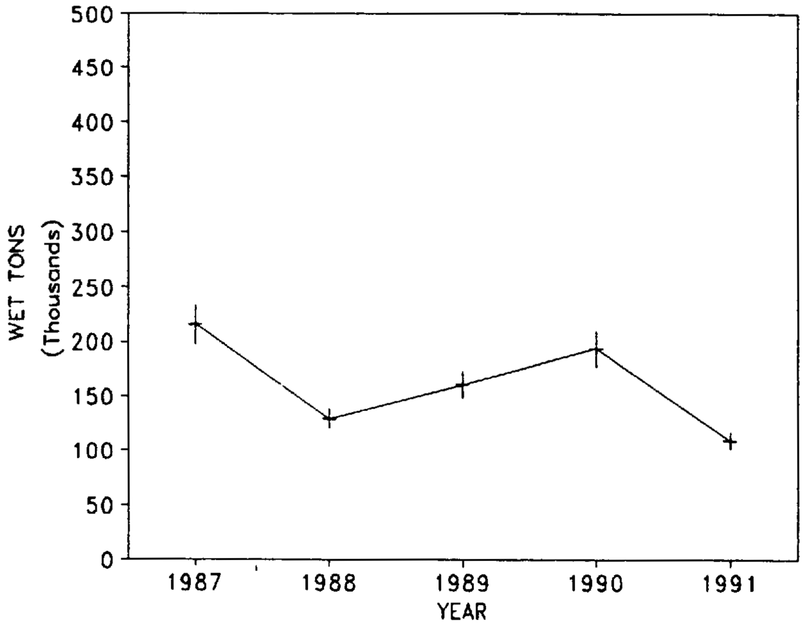


Management

Nonleaded Tank Bottoms



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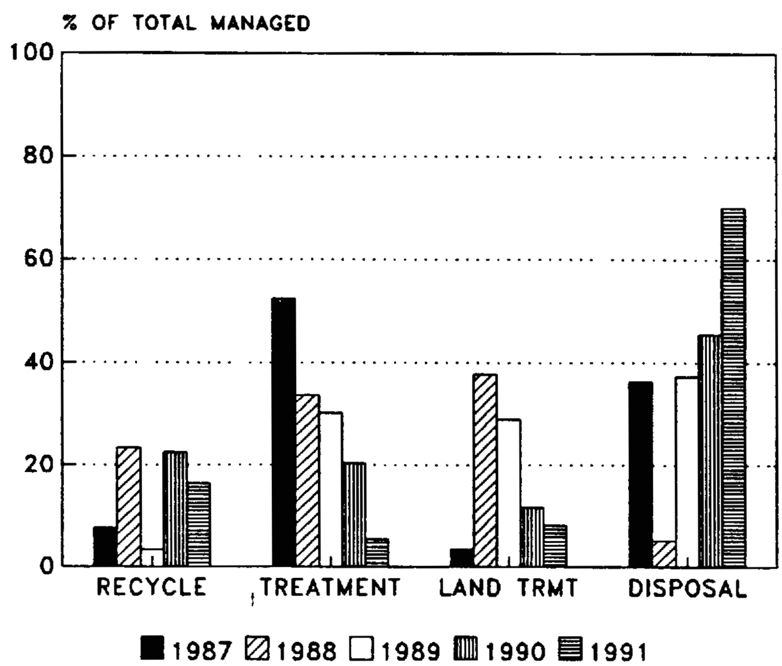
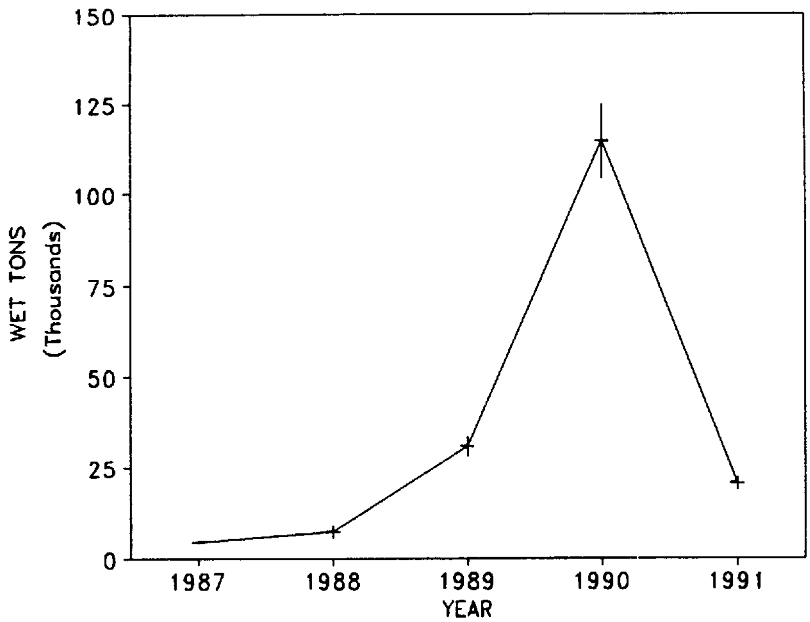


Management

Residual Oils/Spent Solvents



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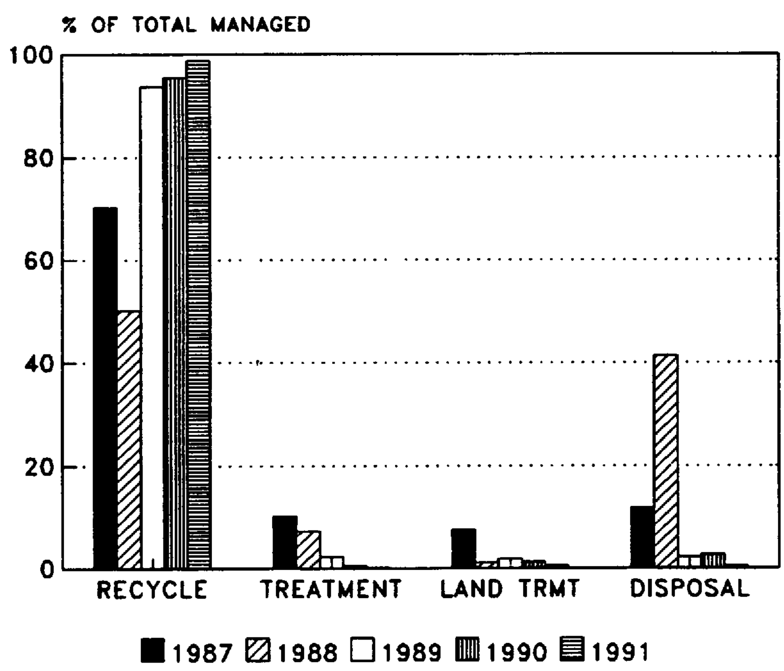
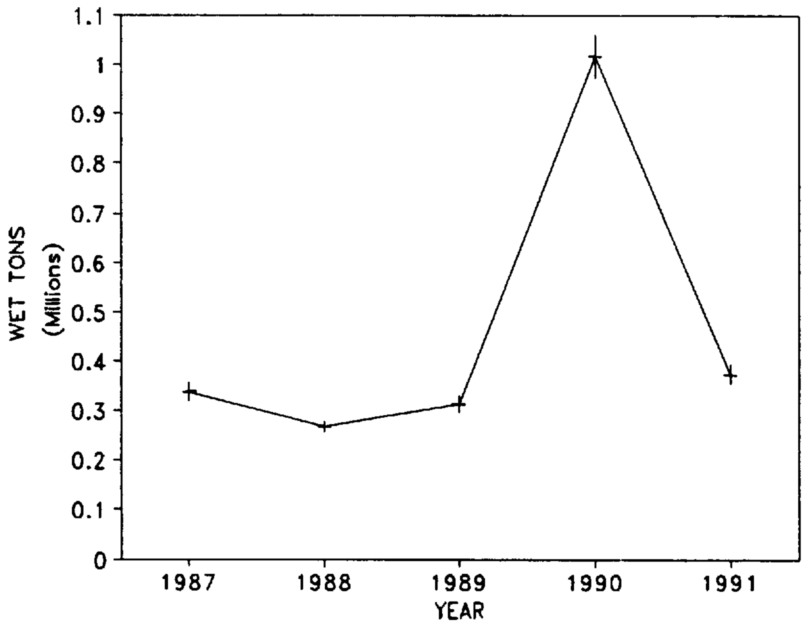


Management

Pond Sediments



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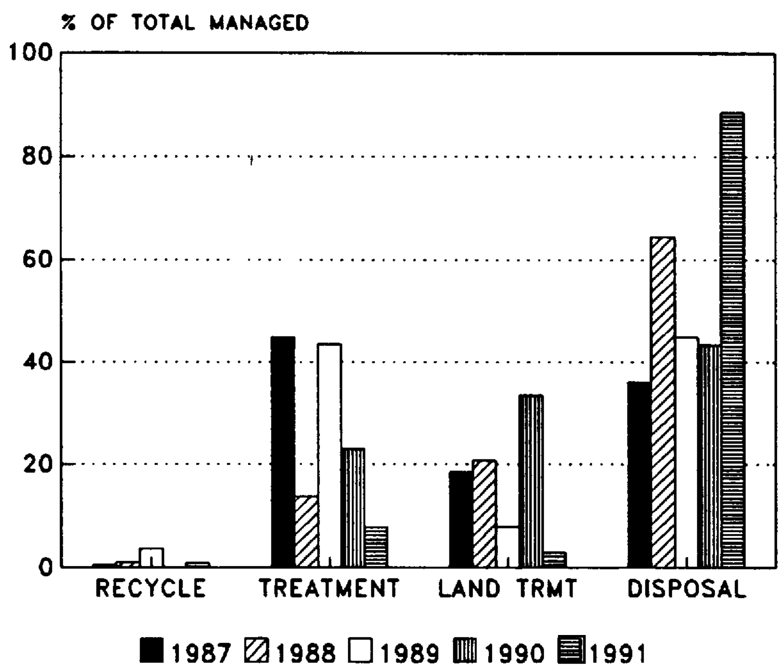
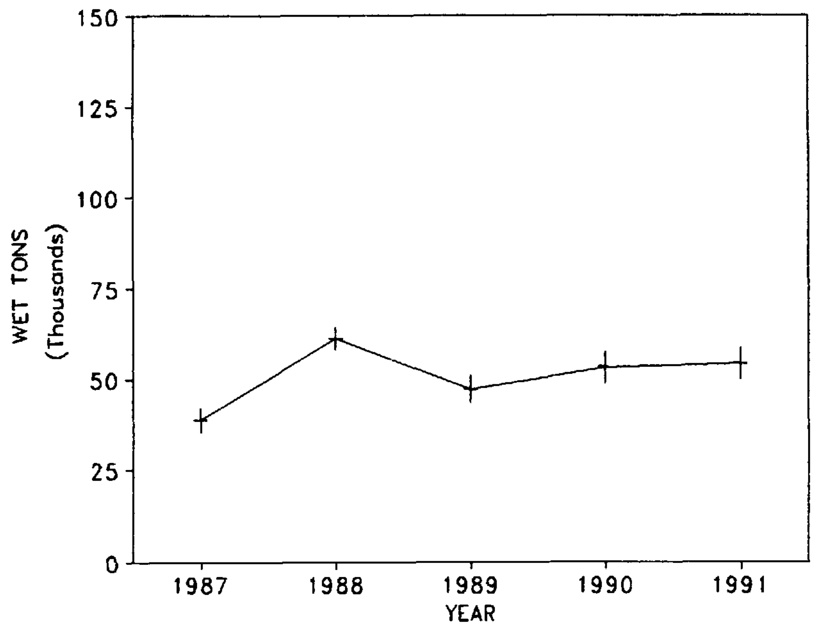
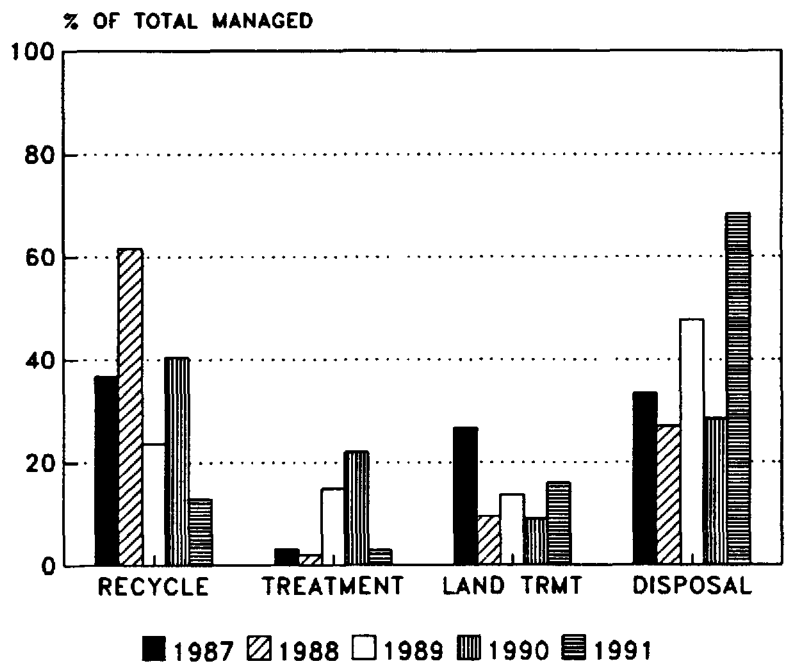


Management

Other Oily Sludges and Organic Residuals

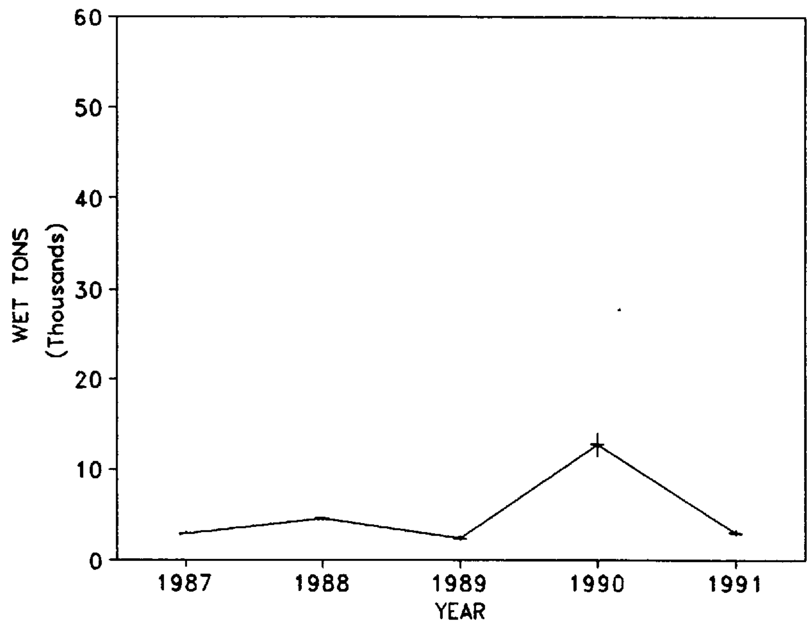


Generation



Management

Heat Exchanger Bundle Cleaning Sludge



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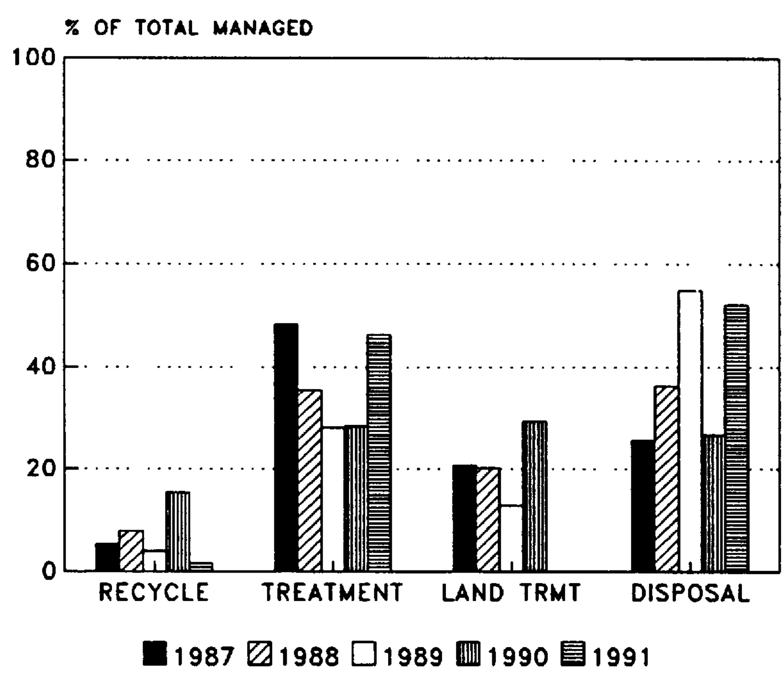
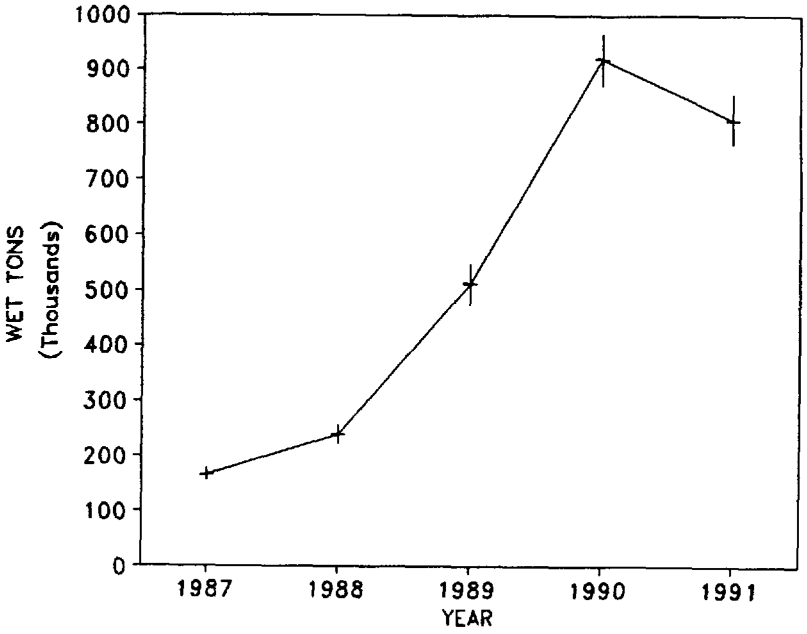
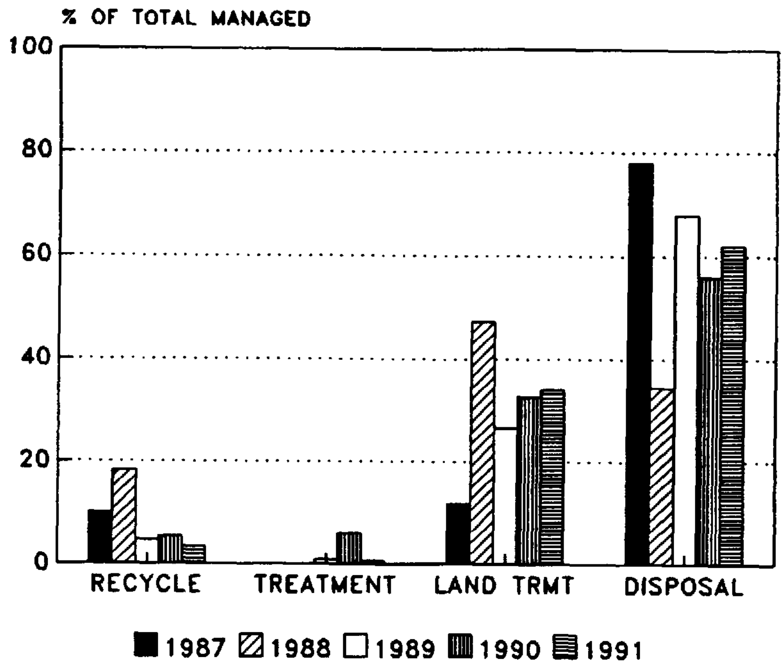


Management

Contaminated Soil/Solids

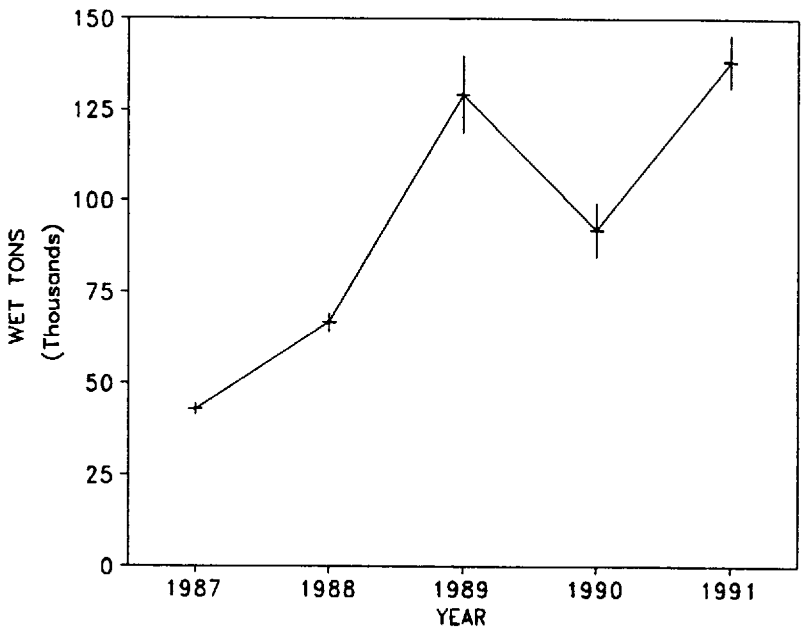


Generation



Management

Residual Coke/Carbon/Charcoal



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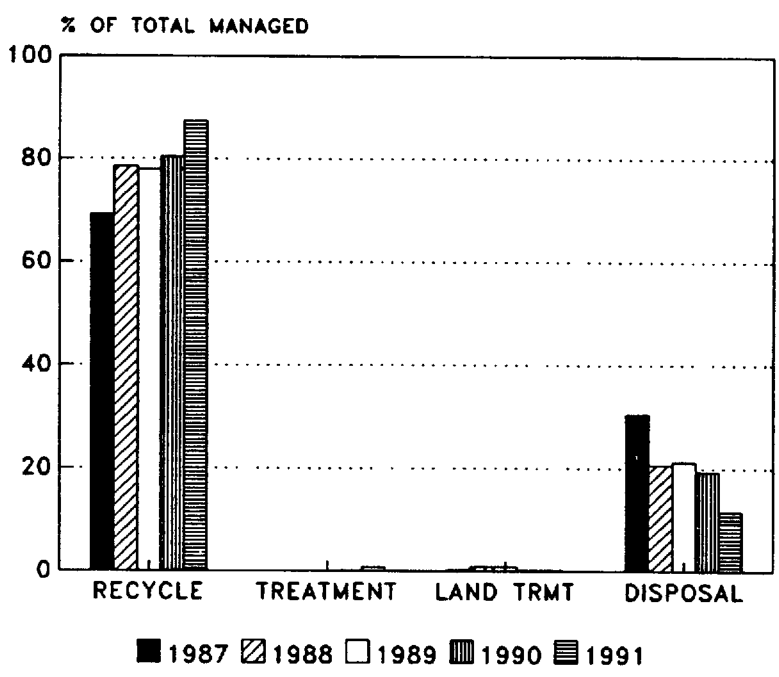
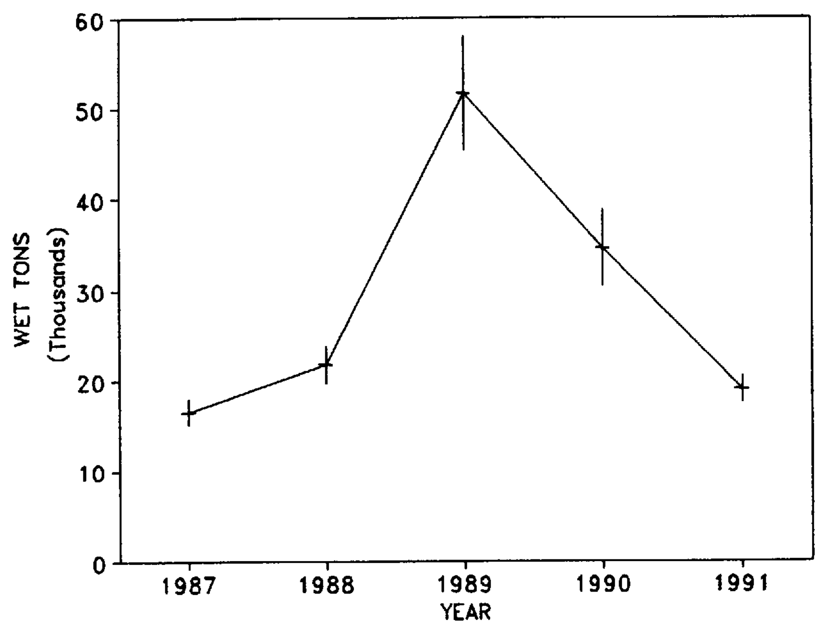


Management

Residual Sulfur



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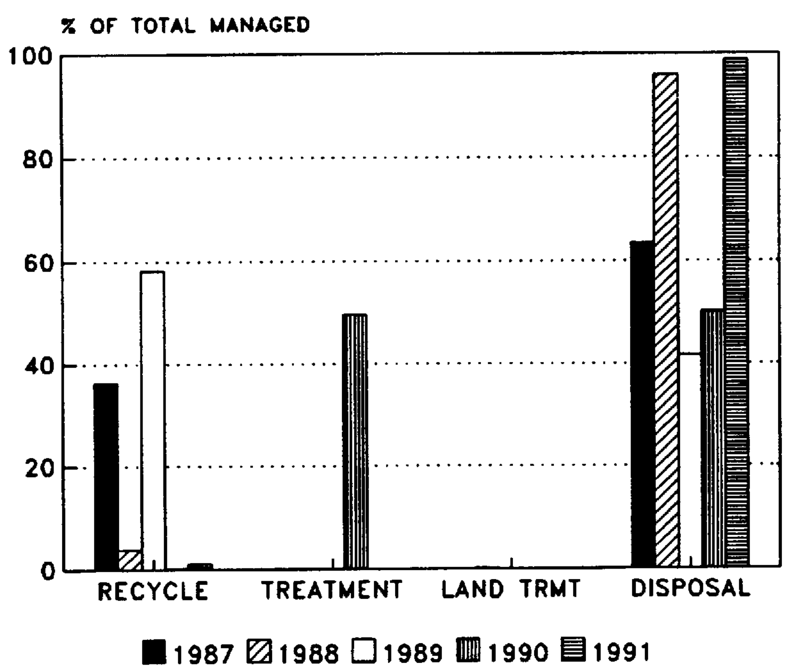
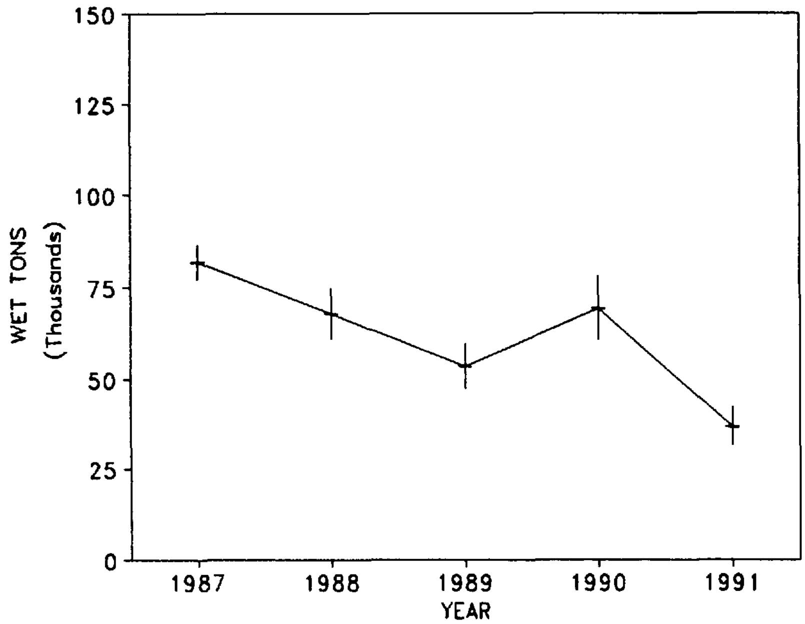


Management

Other Contaminated Soils NOS



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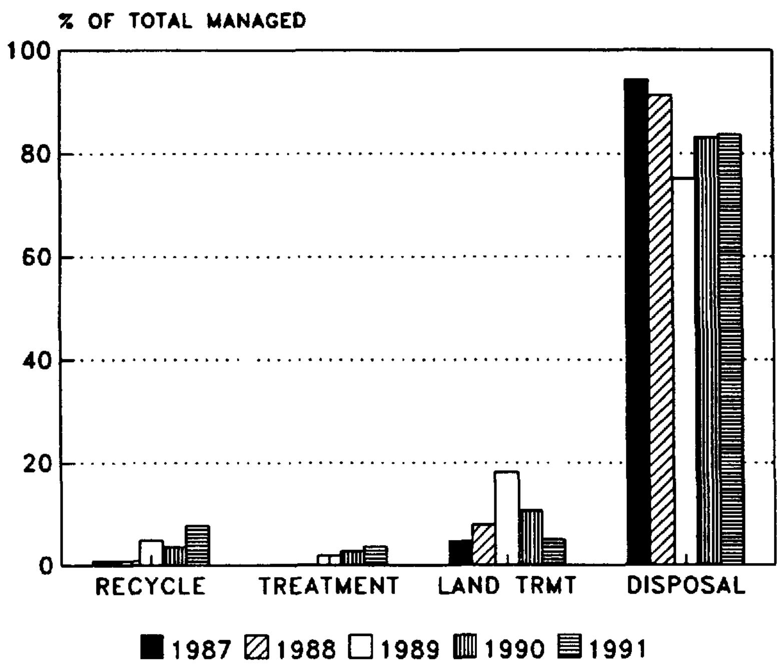
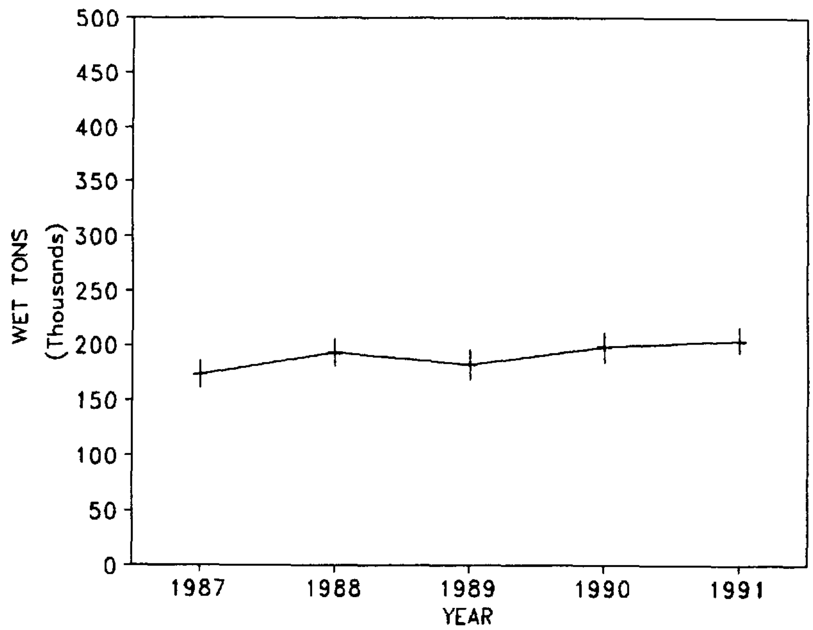


Management

Fluid Cracking Catalyst or Equivalent



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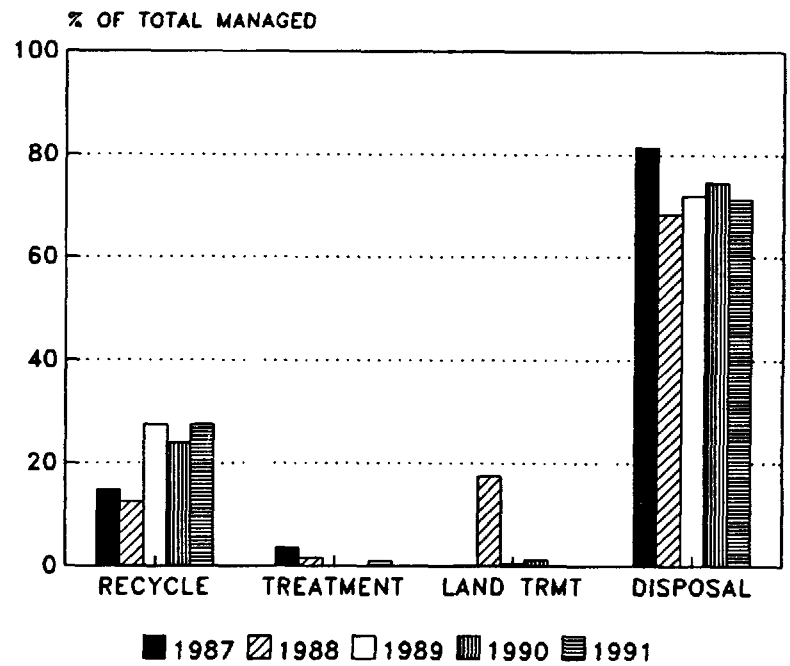
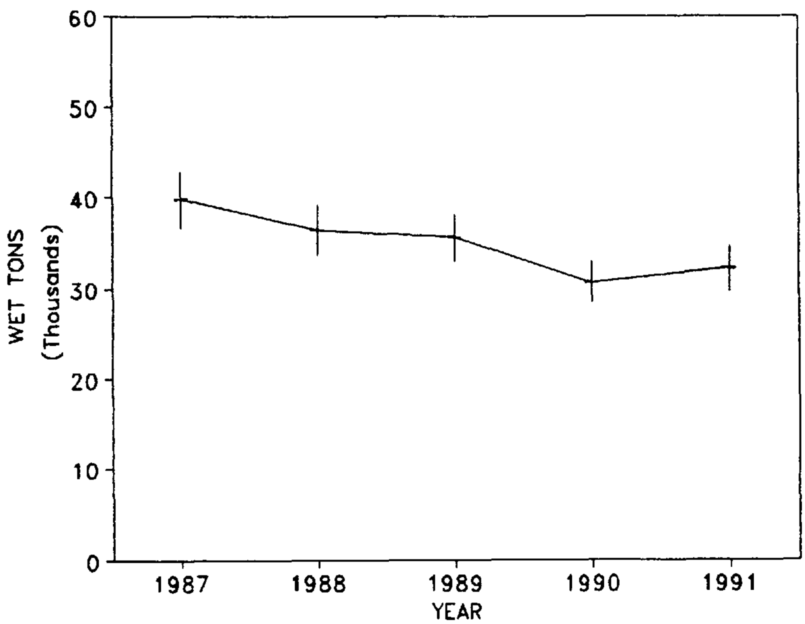


Management

Hydroprocessing Catalysts



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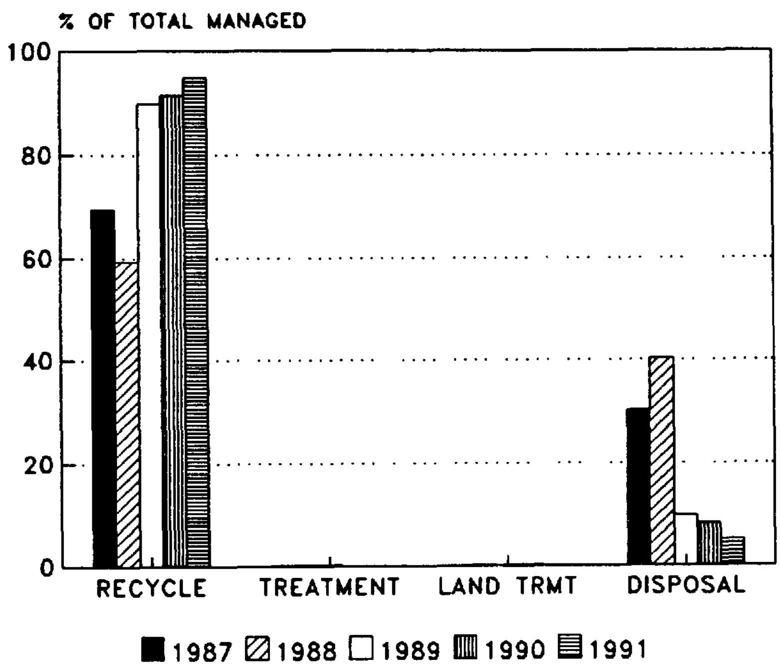
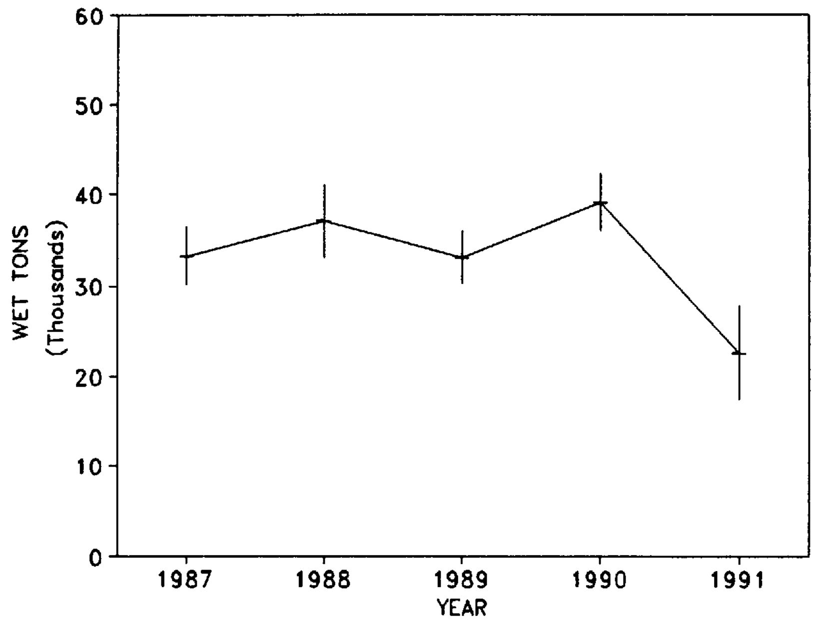


Management

Other Spent Catalysts NOS



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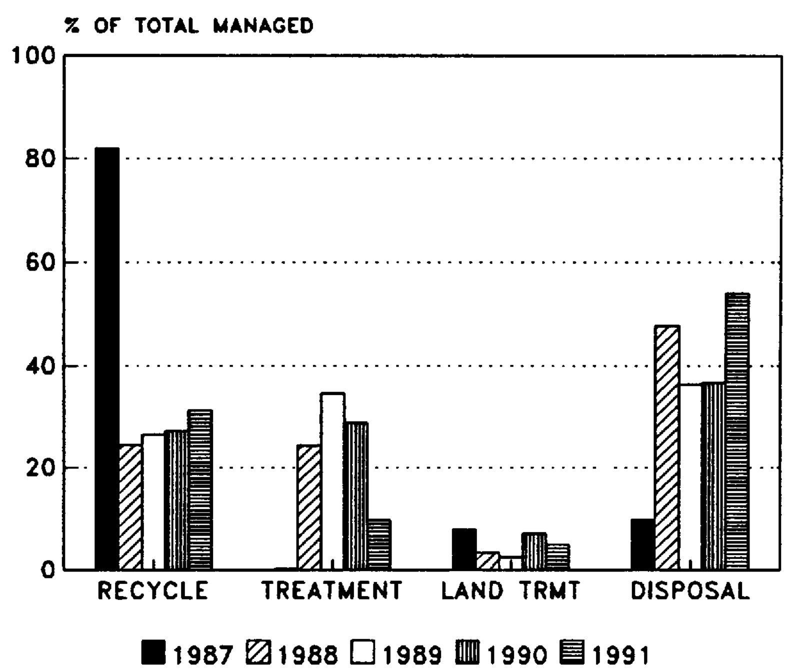
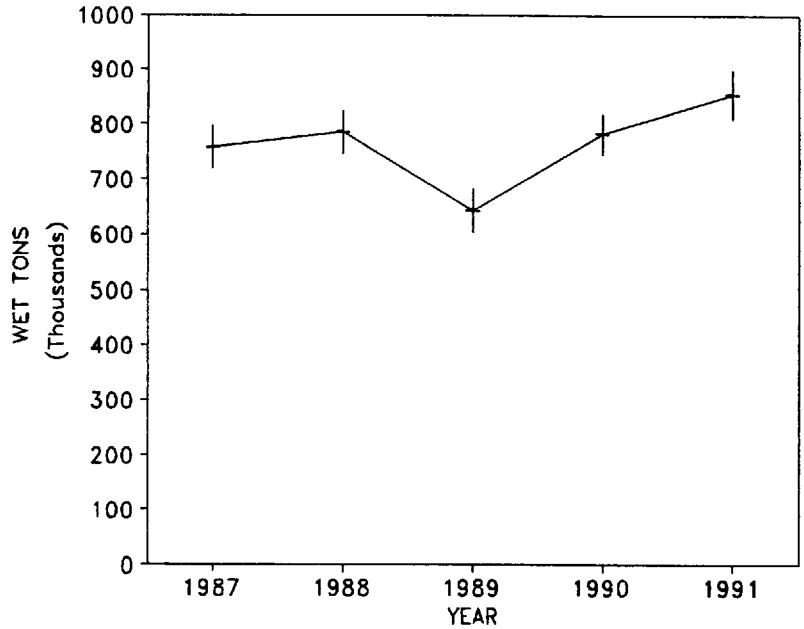


Management

Biomass



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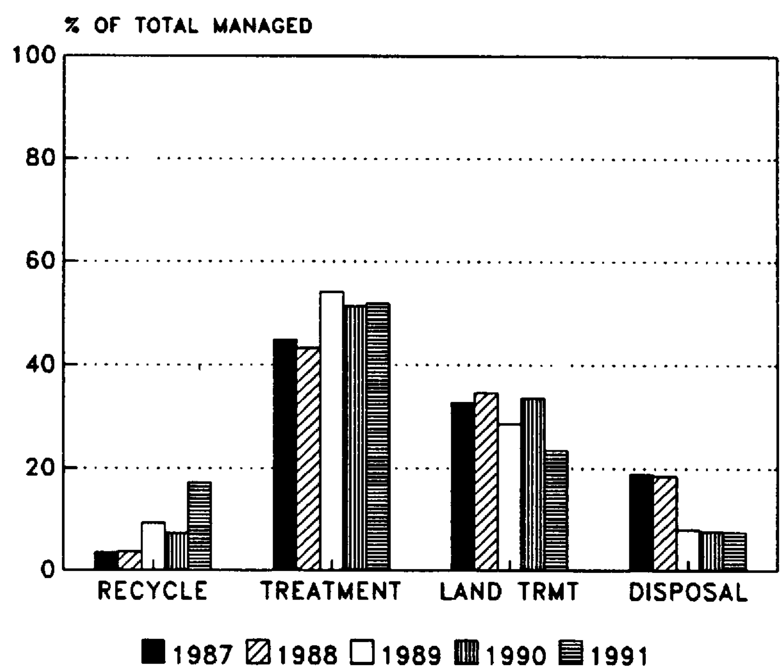
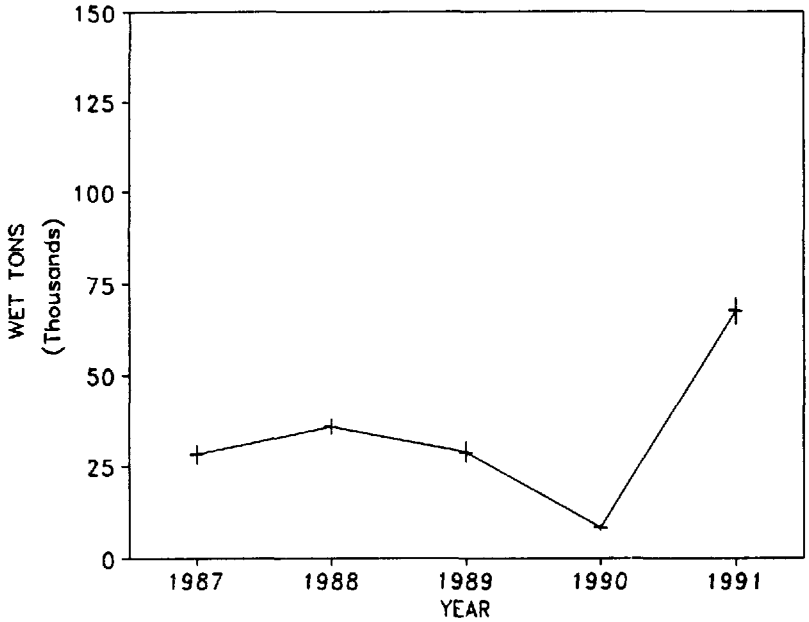


Management

Oil Contaminated Water Not Wastewater



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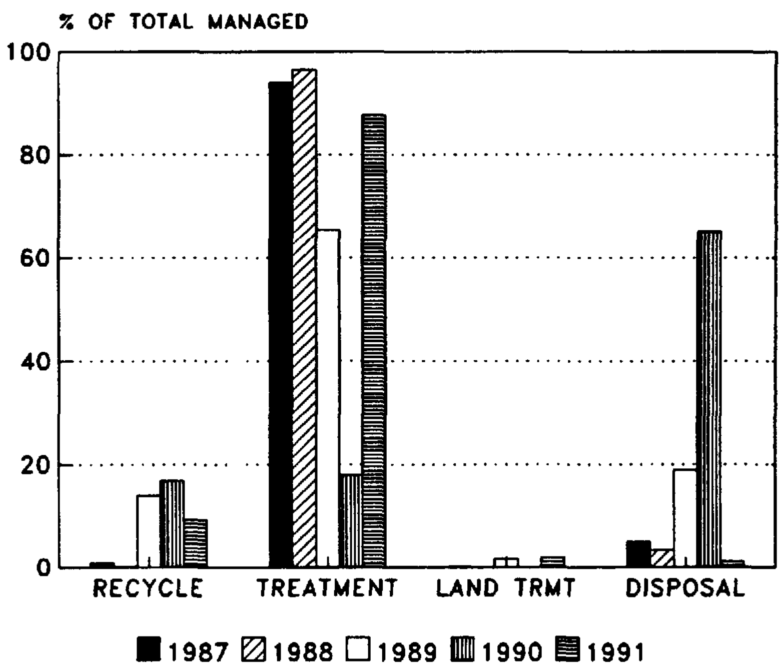
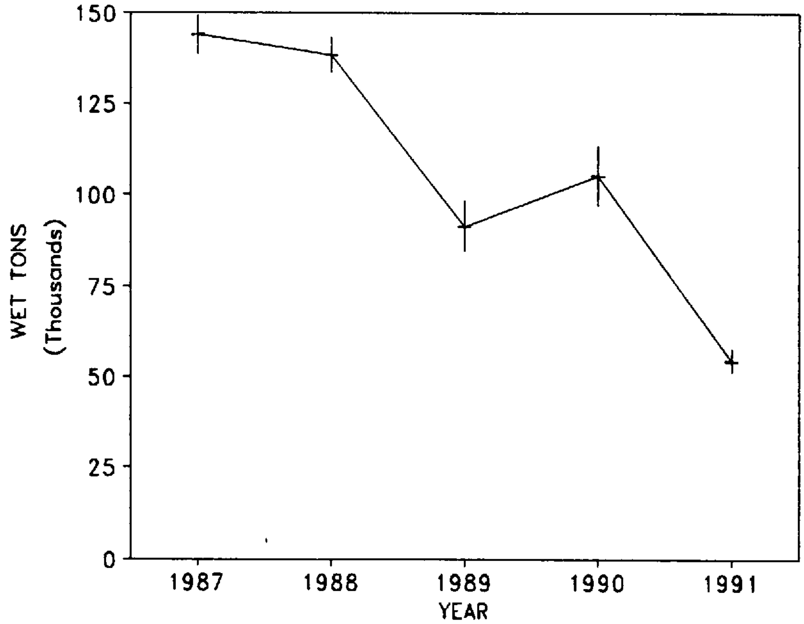


Management

High pH/Low pH Waters



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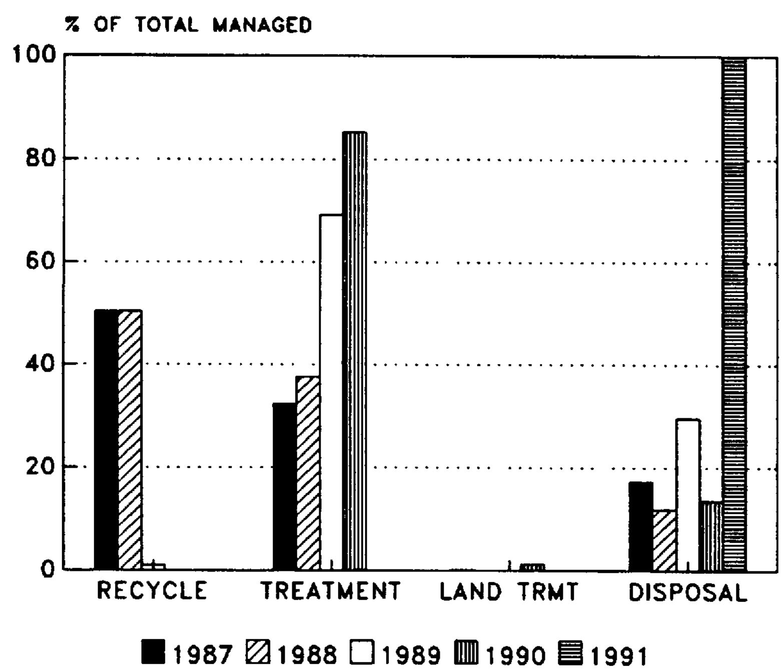
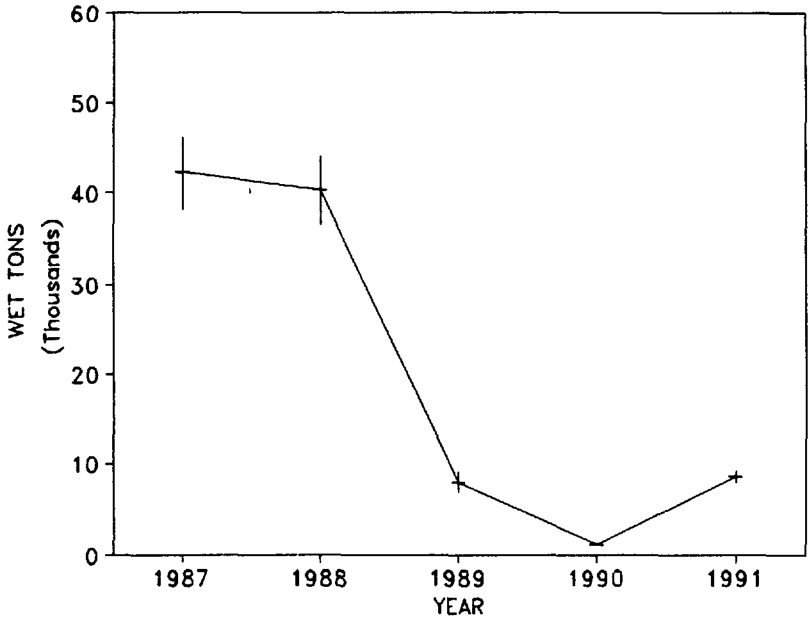


Management

Spent Sulfite Solution



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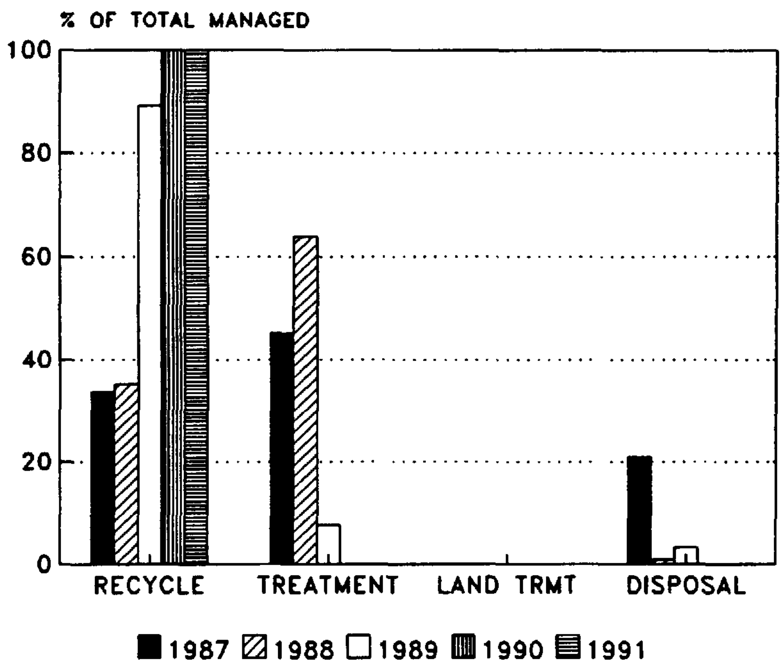
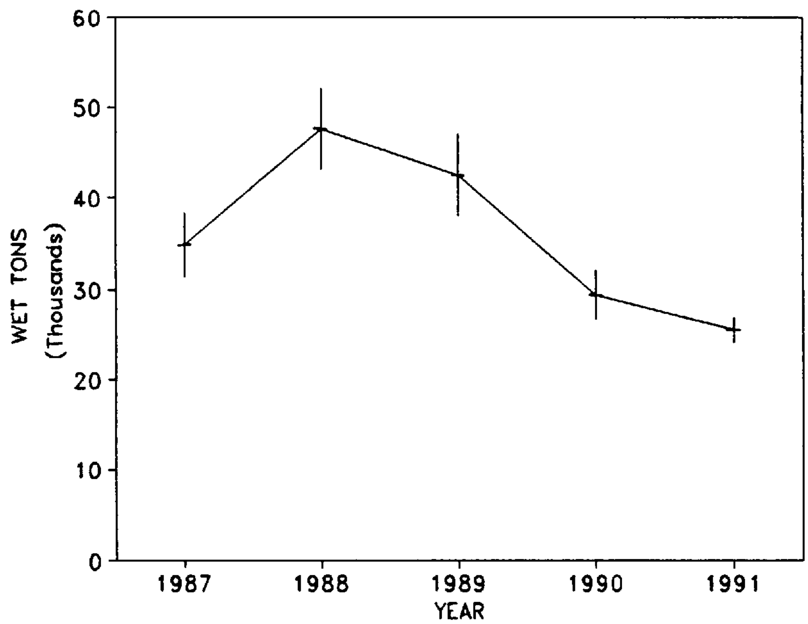


Management

Spent Stretford Solution



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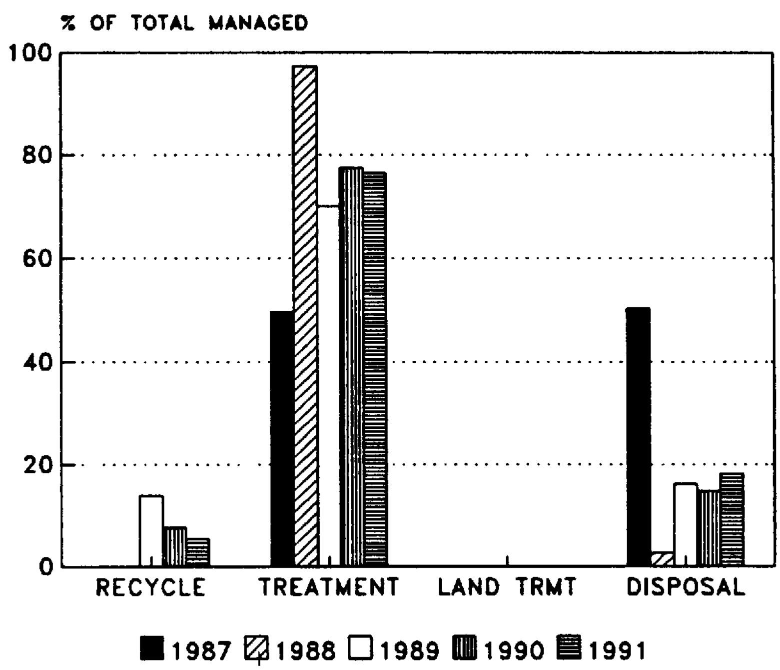
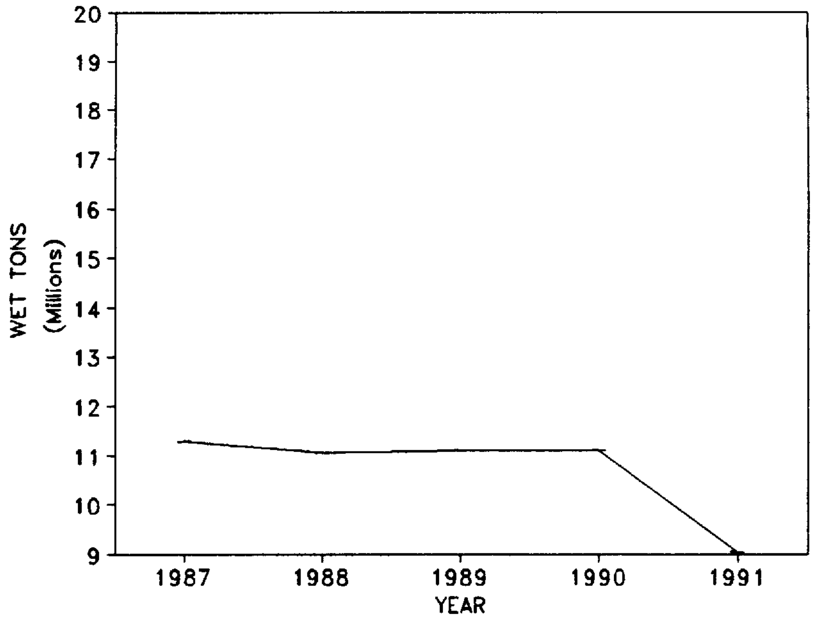


Management

Other Aqueous Residuals NOS



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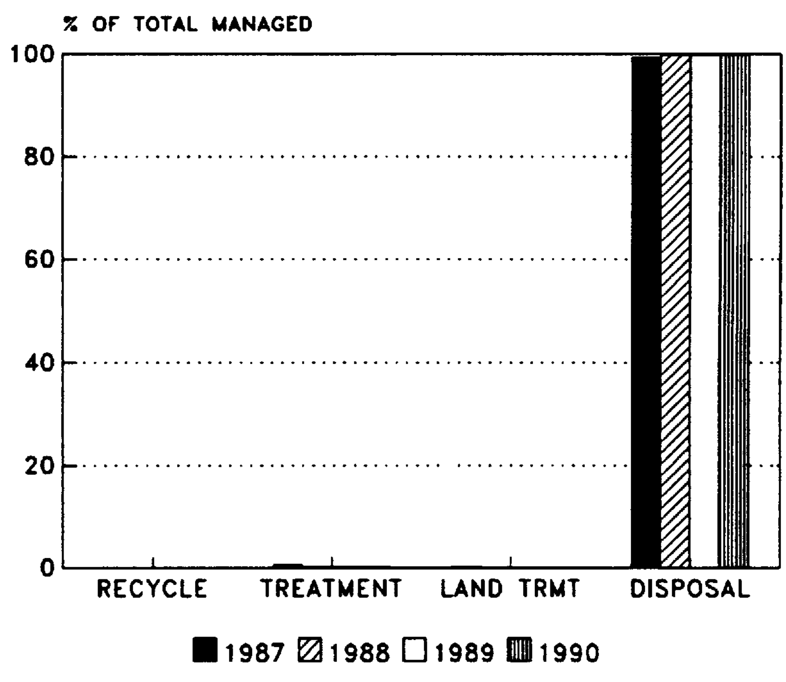
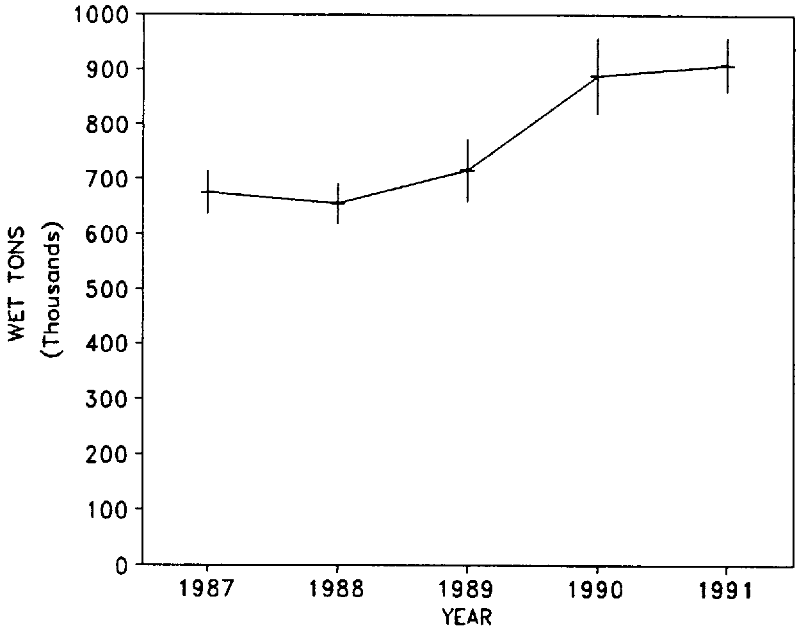


Management

Spent Caustics



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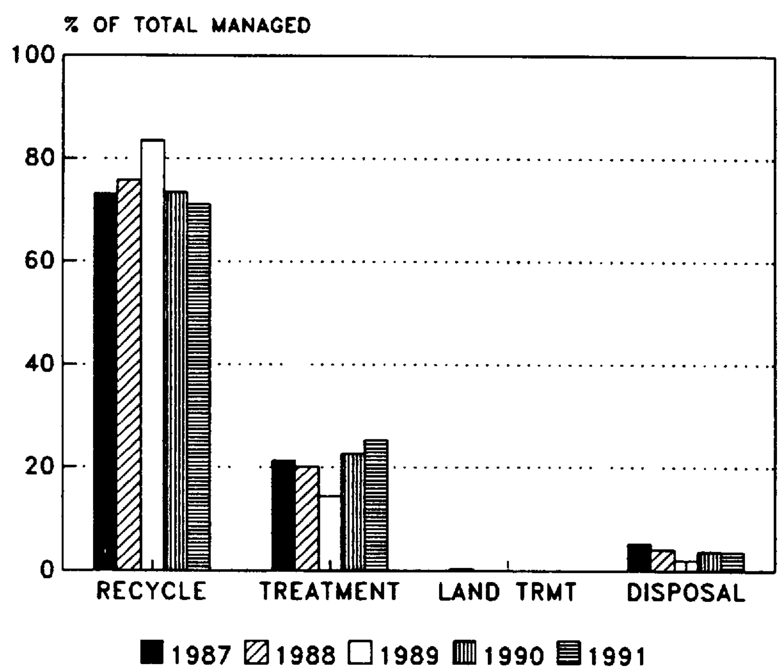
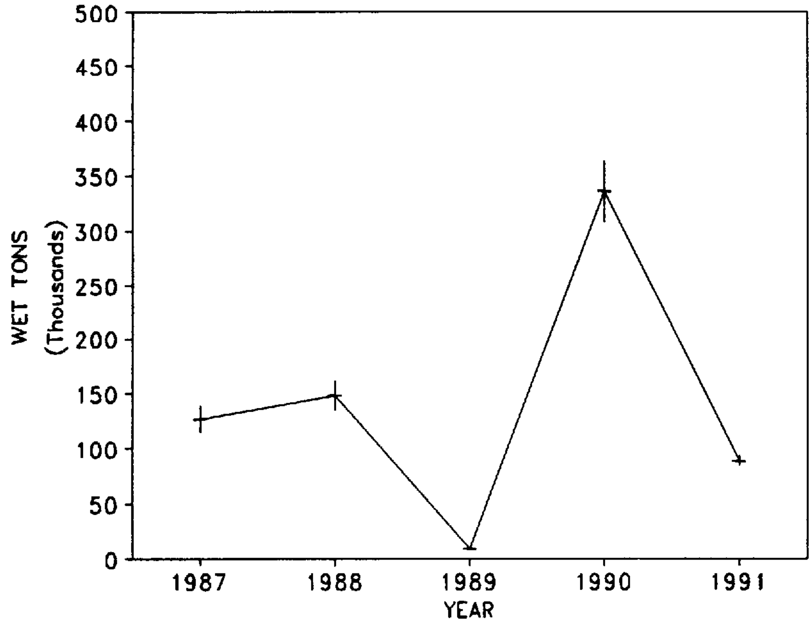


Management

Spent Acids



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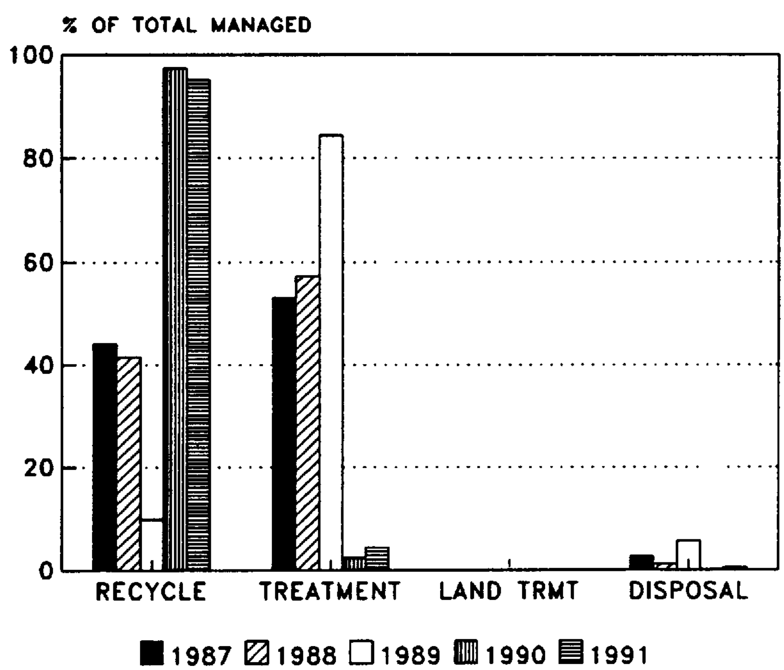
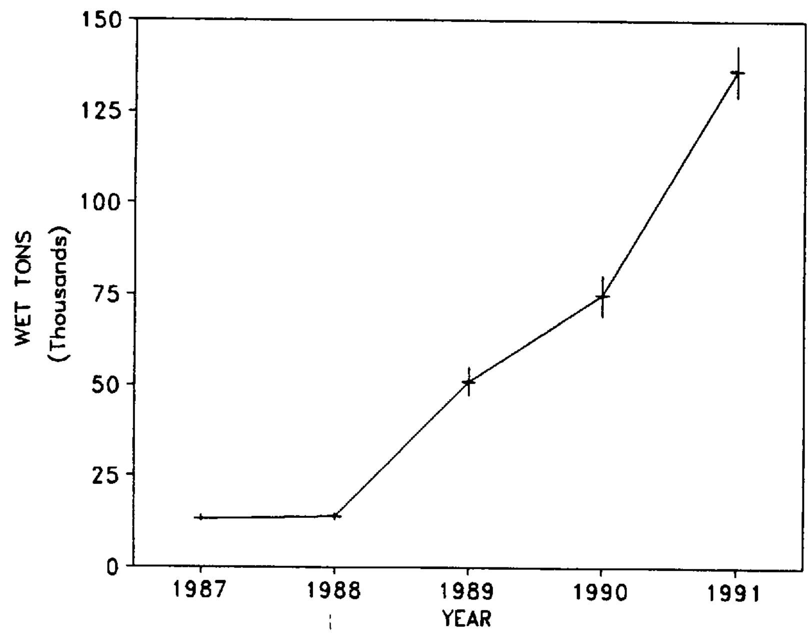


Management

Residual Amines



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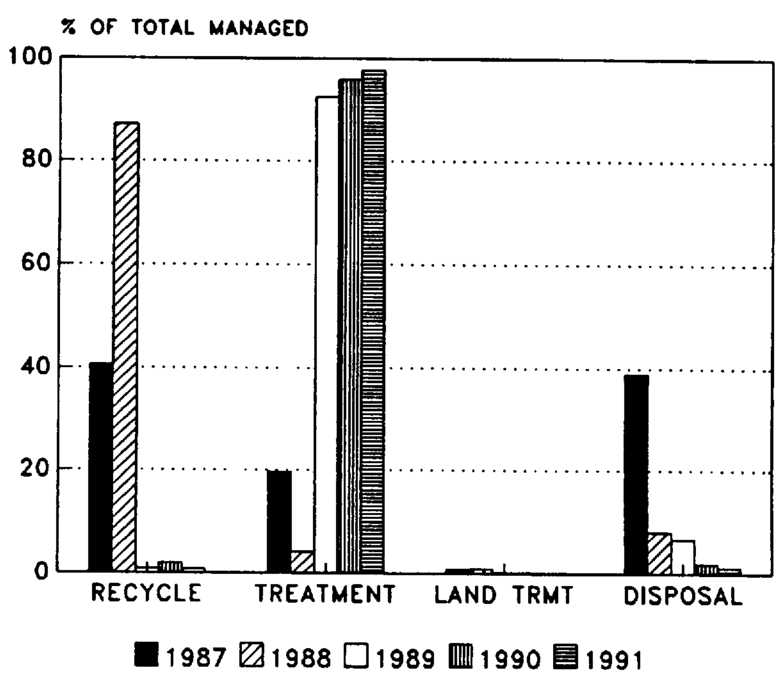
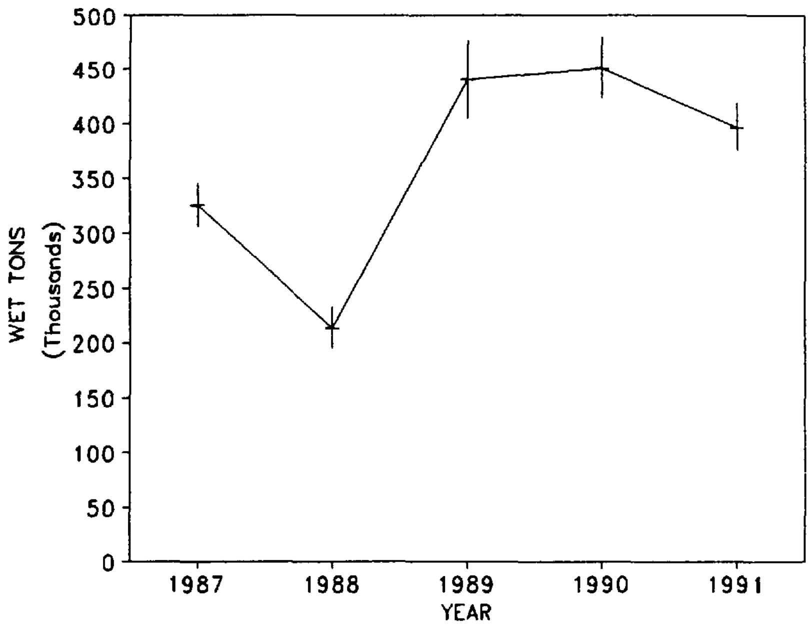


Management

Other Inorganic Residuals NOS



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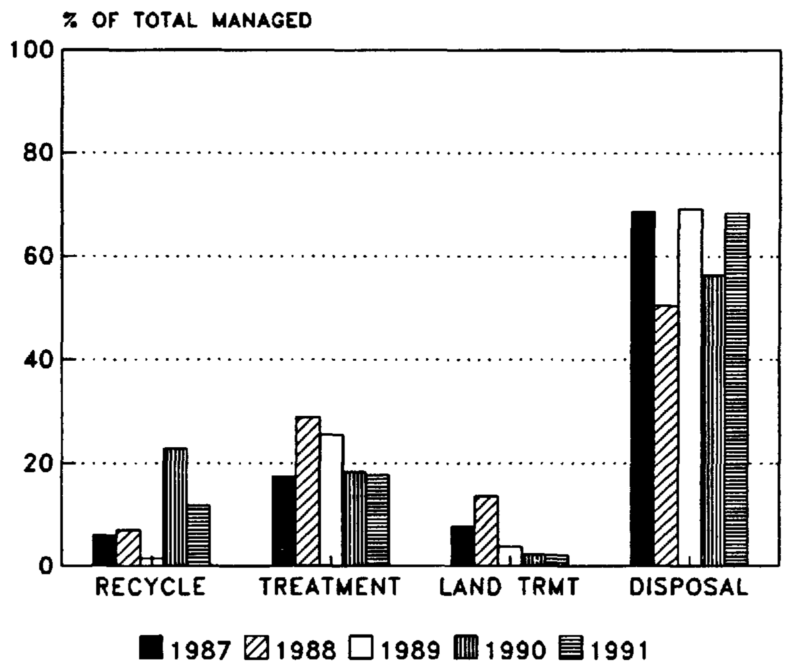
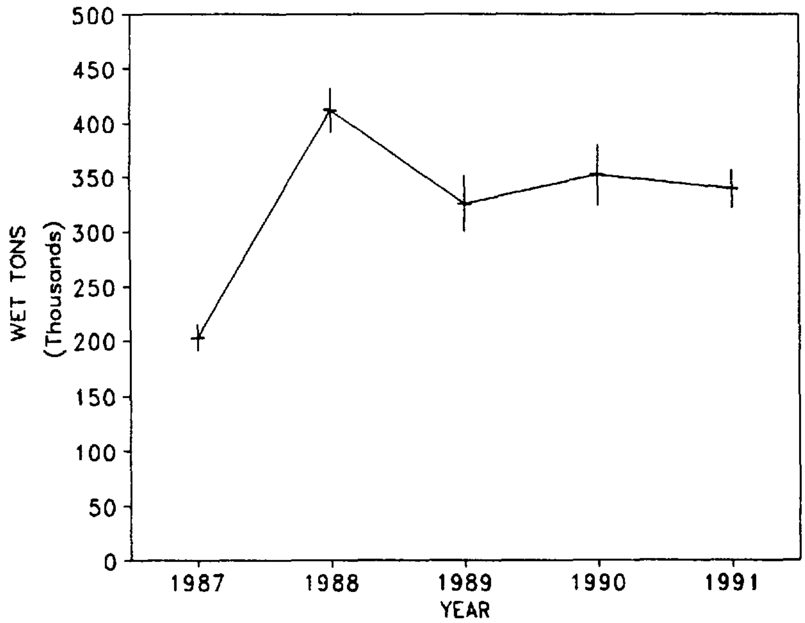


Management

Other Residuals NOS



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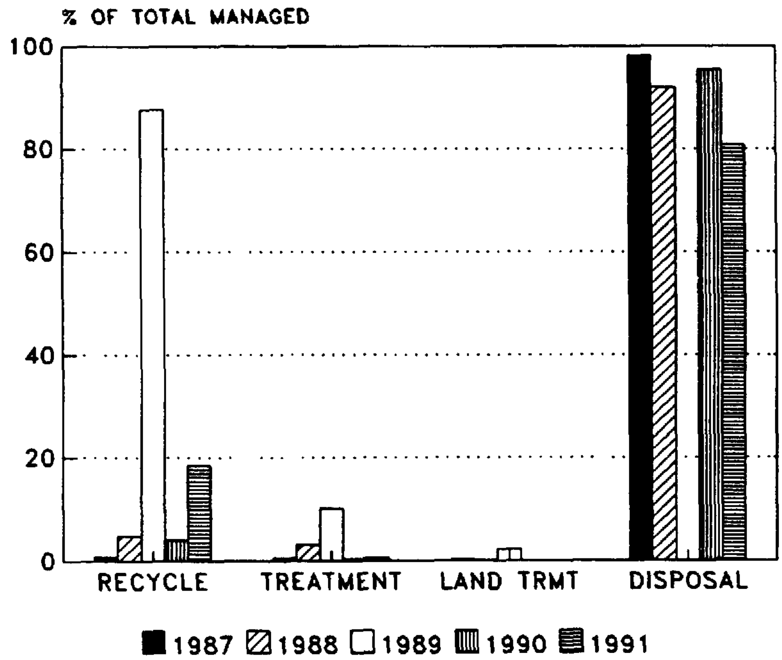

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