American Petroleum Institute

STEP
Strategies for Today's Environmental Partnership

MANAGEMENT OF RESIDUAL MATERIALS: 1995

PETROLEUM REFINING PERFORMANCE

HEALTH AND ENVIRONMENTAL AFFAIRS DEPARTMENT
PUBLICATION NUMBER 339
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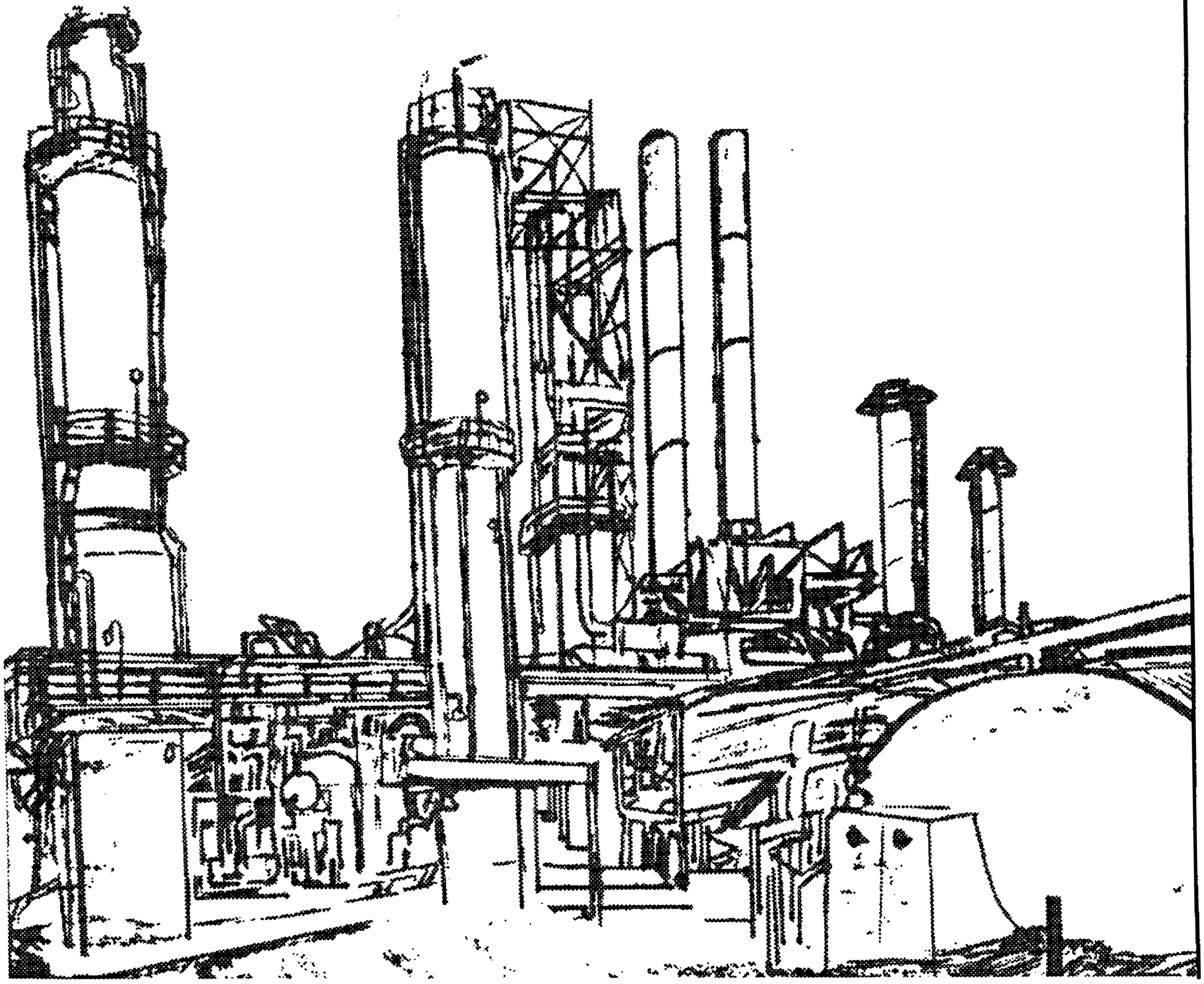

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STEP

Strategies for Today's Environmental Partnership

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- To advise promptly, appropriate officials, employees, customers and the public of information on significant industry-related safety, health and environmental hazards, and to recommend protective measures.
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- To work with others to resolve problems created by handling and disposal of hazardous substances from our operations.
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- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.

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Management of Residual Materials: 1995

Petroleum Refining Performance

Health and Environmental Affairs Department

API PUBLICATION NUMBER 339

PREPARED UNDER CONTRACT BY:

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At each refinery participating in the survey, one or more individuals assumed the responsibility to complete the survey questionnaire. Their efforts deserve special recognition and thanks from the industry.

Carol Gosnell (API) is recognized for her contribution to the cover art for this publication.

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EXECUTIVE SUMMARY

The 1995 API Refining Residual Survey collected data on the manner in which U.S. petroleum refineries manage their residual materials. This report summarizes the characteristics of the facilities that responded, and presents nationwide trends in residual management practices. The nationwide estimates were determined from a regression analysis of the respondent data in terms of residual quantity in wet tons by refinery capacity in barrels per stream day (bsd).

1995 Refining Residual Survey–Response Level

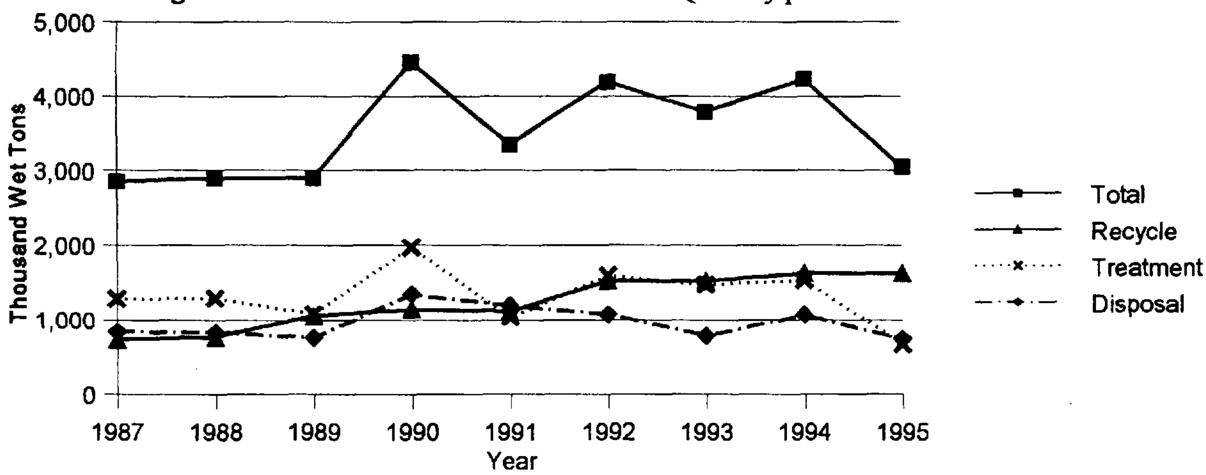
	Estimated U.S. Total	Survey Respondents	Percent
No. of Facilities	149	74	50 %
Refining Capacity	15,006,371 bsd	8,257,071 bsd	55 %
Residual Quantity	3,049,000 wet tons	1,708,452 wet tons	56 %

The 1995 survey collected data on the management of 14 residual streams, believed to represent nearly 80% of the total quantity of residuals managed at U.S. refineries, and requested cost data on six of those streams. As with previous surveys, data were collected on the age, size, location, and type of refinery, and on the configuration of the wastewater treatment systems.

DIFFERENCE FROM PRIOR YEAR RESULTS

Efforts in this year's survey to collect more consistent data resulted in significant departures from prior years' data trends. Some facilities had previously reported the quantity of residual generated prior to dewatering, while others had reported the quantity managed after dewatering. This year's survey specified that only the quantity of residual remaining after dewatering was to be reported, without the recovered water or oil, thus providing for a consistent basis of response and more accurately reflecting quantities of residuals managed. In the following chart, the data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

Trends in Management Practices–Nationwide Estimates of Quantity per Year



The specific adjustments made to prior years' data were to delete the amounts shown as managed by wastewater treatment from the streams that are reduced by dewatering, which are the *tank bottoms*, *API separator sludge*, *DAF float*, *primary sludges*, *slop oil emulsion solids*, *biomass*, and *pond sediments* streams. Amounts listed as recycled to a crude unit were deleted from these same streams, with the exception of *DAF float* and *slop oil emulsion solids*. The latter two streams had entries in the *crude units*

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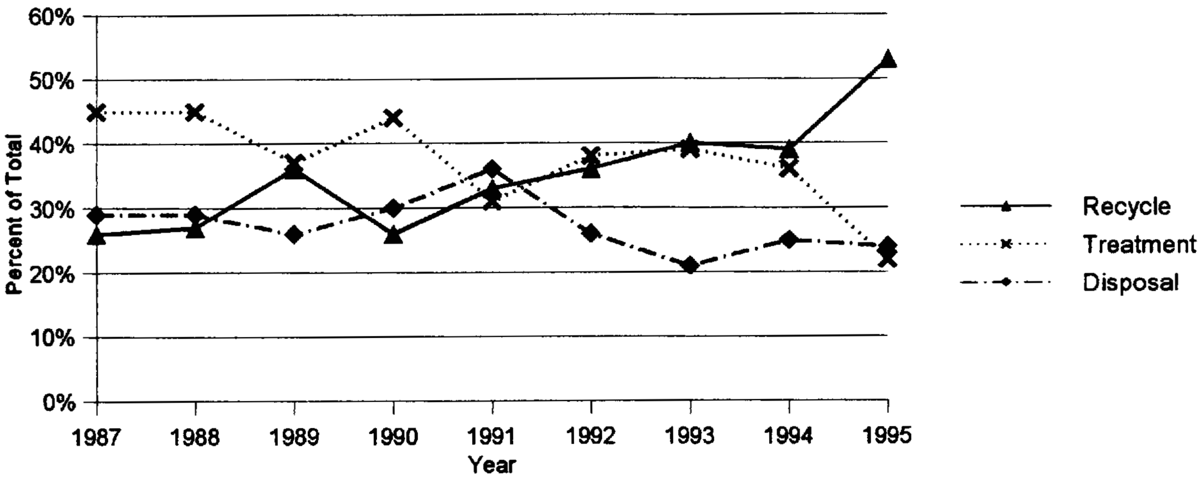
category for 1995, and therefore this category was retained for these two streams in the adjustments of prior years' data.

The estimated total quantity of residuals managed at U.S. refineries dropped from 4,232,000 wet tons in 1994 to 3,049,000 wet tons in 1995, a reduction of 1,183,000 wet tons. The reporting units of wet tons indicate that the stream volumes are taken in their as-managed condition, rather than on a dry-solids basis. While residuals that have been dewatered will have a higher percent-solids content than if they had not been dewatered, they may nevertheless include a significant amount of water.

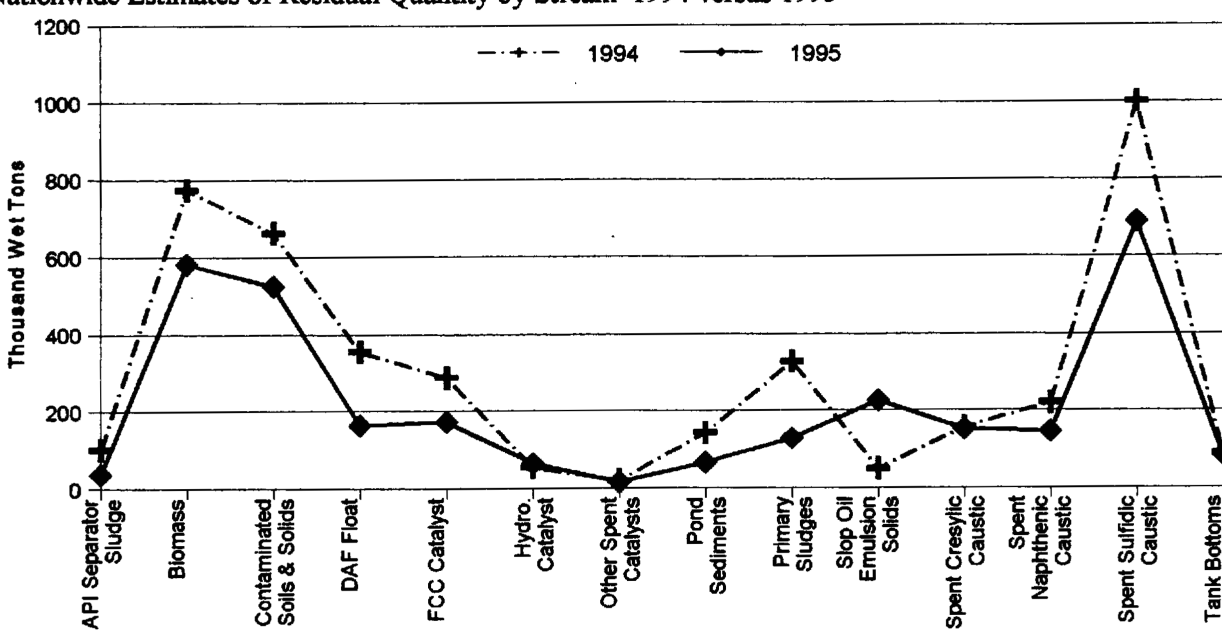
The quantity of residual material reported as having been *recycled* continues the slight upward trend of the previous three years, but as a percent of total it has jumped markedly due to the drop in the other categories. Over half of the total quantity managed is now shown as *recycled.*

Trends in Management Practices–Nationwide Estimates of Percent of Total per Year



The next chart compares residual quantities by stream for 1994 and 1995. The 1994 data have again been adjusted for recovered oil and water to make the data comparable to 1995.

Nationwide Estimates of Residual Quantity by Stream–1994 versus 1995



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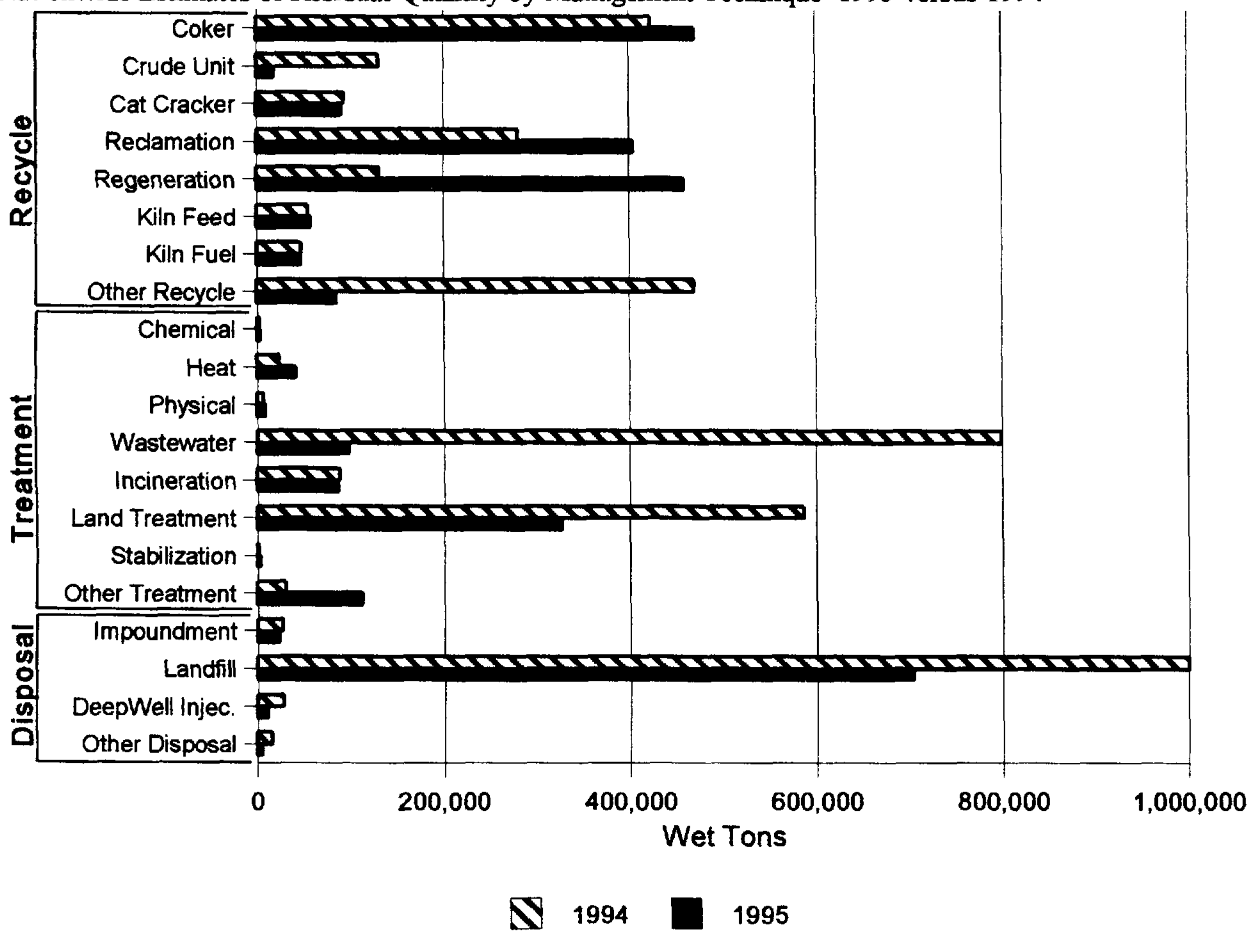
Several facilities reported a combined amount of certain residuals associated with wastewater treatment facilities (i.e., *API separator sludge*, *DAF float*, *primary sludges*, and *slop oil emulsion solids*), in that they commingle these streams for management. The sum of these oily wastewater residuals decreased from 833,000 wet tons in 1994 to 554,000 wet tons in 1995.

Another step taken in the 1995 survey to improve reporting consistency was to combine all manner of *land farming* and *land spreading* into a single *land treatment* category. In the following chart, the quantity reported under *land spread* as a *disposal* technique in 1994 has been combined with *land treatment*, in order to make the data comparable to 1995. As discussed previously, the 1994 data have also been adjusted for recovered oil and water.

Nationwide Estimates of Residual Quantity by Management Technique–1995 versus 1994



The most obvious difference from 1994 to 1995 is the 88% decrease in the amount managed by *wastewater treatment*. Much of this decrease occurred in the quantities reported for *spent sulfidic caustic*, which were offset in part by an increase in the amount of this stream that was *regenerated*.

There was also a marked drop off in the estimated quantity of residuals managed by *land treatment*, which was almost entirely attributable to reduced amounts of *biomass* being *land treated*. There was, however, a new entry for *biomass* being managed by *other treatment*. This arose from one facility reporting management of *biomass* by *sludge digestion*.

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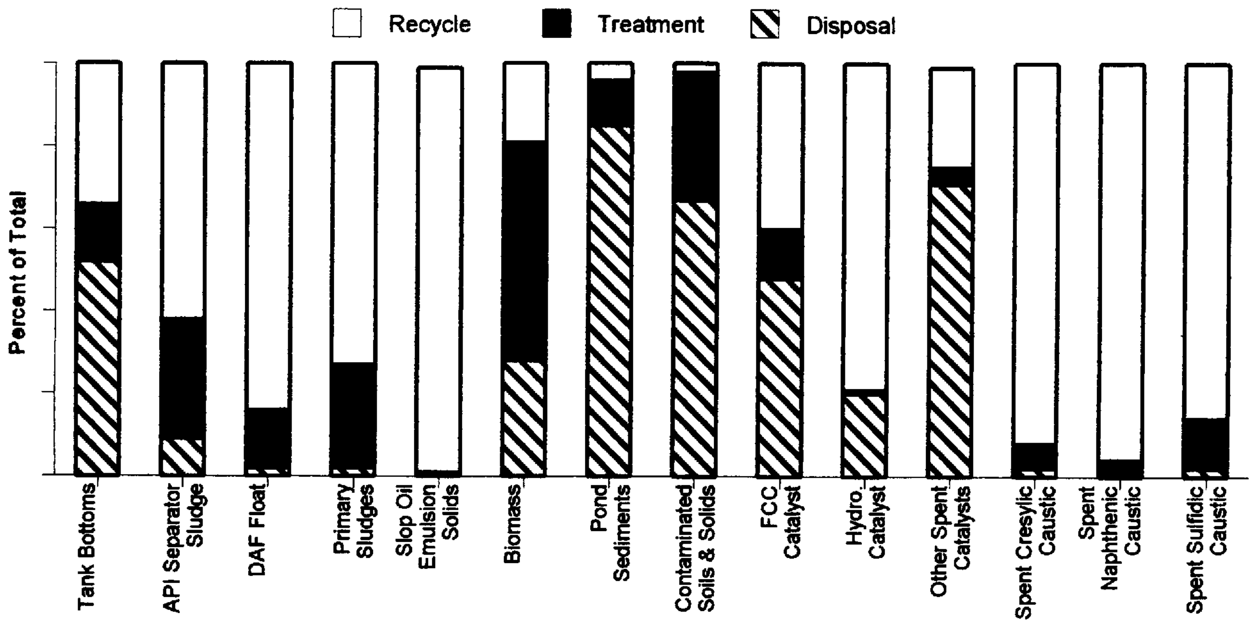
The reduction in the estimated quantity of residuals being *landfilled* included a near-elimination of the *landfilling* of *primary sludges*.

The next chart displays the nationwide distribution by management practice for each stream, as estimated from the 1995 survey. The streams that are sometimes dewatered, which include *tank bottoms*, the *oily wastewater* residuals, *biomass*, and *pond sediments*, are on the left side of the chart.

Nationwide Estimates of Distribution by Management Practice–1995



Much of the difference in the survey results for 1995 versus previous years is due to improved consistency in the reporting methods. It is evident nonetheless that the reported quantity of residual material managed by U.S. refineries has decreased by more than a million wet tons, and *recycling* has become the dominant management practice.

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Section 1
METHODOLOGY

LISTING OF REFINERIES

The term 'petroleum refinery' is used differently in various contexts. For purposes of the 1995 API Refining Residual Survey, a refinery is defined as a facility that currently processes crude oil. Facilities that do not have crude units are not included in the survey.

The 1995 survey was distributed in electronic format (i.e., computer software on diskettes). While electronic formats had been attempted previously, this survey was the first in which respondents were required to enter their data on a computer and return the data to API on a diskette. A copy of selected screens from the electronic survey form is presented in Appendix A.

The survey was sent initially to a mailing list maintained by API. Additional facilities were identified from the API Publication *Entry & Exit in U.S. Petroleum Refining, 1948-1995* and from the list of *Worldwide Refineries-Capacities as of January 1, 1995* published by the Oil & Gas Journal. A total of 145 refineries received the survey, of which 74 responded. The list of refineries was updated further prior to analyzing the data, resulting in 149 facilities being included in the data analysis. The 74 respondent refineries represent 55% of the nationwide refining capacity.

RATIONALE FOR SURVEY CLARIFICATIONS

It became apparent during the preparation of the 1995 survey that several aspects of prior years' surveys had been interpreted inconsistently by respondents. For example, while many facilities had properly reported the quantity of residuals that remained after dewatering as that which was subsequently managed, other facilities had additionally listed the quantities and disposition of the recovered oil and water. This resulted in such curious responses as showing *primary sludge*, which is a residual removed from the wastewater plant, as being managed by *wastewater treatment*, which would imply that it was managed by returning it to the wastewater plant. In actuality, it was not the *primary sludge* residual that was managed by *wastewater treatment*, but rather it was water recovered from a dewatering process. This same water may then be bound in more *primary sludge* and again removed by dewatering and recycled back to the wastewater plant. The quantities of the dewatered streams, then, were being distorted by recovered oil and water which were cycled within the facility, in addition to the actual residual quantities that were managed. This year's survey specified that only the quantity of residual remaining after dewatering was to be reported, without the recovered water or oil, thus providing for a consistent basis of response and more accurately reflecting quantities of residuals managed.

The quantity reported for each stream, then, was that remaining after any dewatering of the sludge. For those streams that are not defined as RCRA-listed hazardous wastes, the quantity may include both hazardous and nonhazardous materials. Where it was determined that a facility had reported both the quantity of material that was treated and the quantity that was disposed of after treatment, only the quantity treated was included in the analysis.

The reporting units of wet tons indicate that the stream volumes are taken in their as-managed condition, rather than on a dry-solids basis. While residuals that have been dewatered will have a higher percent-solids content than if they had not been dewatered, they may nevertheless include a significant amount of water.

It was determined that respondents previously had different interpretations of the definitions of the

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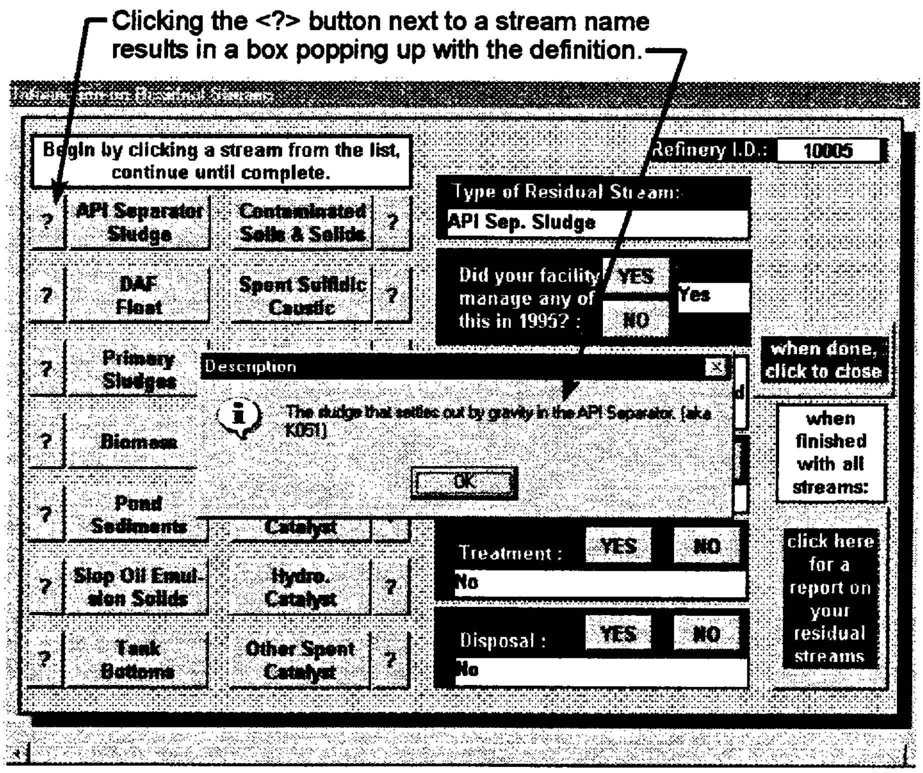
individual residual streams. In order to facilitate consistency of response, definitions were added to the 1995 survey as pop up messages attached to buttons on the survey form, as shown in the following figure.

Figure 1—Sample Screen from the Survey Form



RESIDUAL STREAMS

Earlier annual surveys had collected data on 30 separate residual streams, but the 1994 survey reduced the number of streams to 15 for simplification. These 15 streams were believed to represent approximately 80% of the total quantity of refinery residuals. The 1994 survey had included two separate categories for *primary sludges* (i.e., the F037 and F038 RCRA categories). Combining these two streams into a single *primary sludges* category resulted in 14 streams in the 1995 survey. The 1995 survey also collected information on the cost of managing six of the 14 streams in the survey, compared to three streams having had cost data questions in the 1994 survey. The 14 residual streams in the 1995 survey and the definitions assigned to each are listed in Appendix A.

It should be understood that the residual stream labels used in this survey are NOT used in a regulatory sense. Whereas the Environmental Protection Agency (EPA) regulations implementing RCRA have given these terms special meaning, the usage here is in a broader, more generic sense. API's intent is to have survey participants report the management of all residual type materials (e.g., materials that are byproducts or residuals of petroleum refining operations). This includes residuals that are beneficially recycled or reclaimed, as well as materials that are discarded.

MANAGEMENT PRACTICES AND TECHNIQUES

The 1995 survey continued to group management techniques into three categories of management practice–recycling, treatment, and disposal. As with the residual streams, however, it was found that there was substantial variation in the understood definitions of the individual management techniques. Again,

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definitions were added to the survey form as pop up messages. The management techniques from the 1994 and 1995 surveys, with the definitions assigned to them for the 1995 survey, are listed in Appendix A. *Each of these management techniques is allowed under certain regulatory scenarios.*

DATA ANALYSIS

Completed survey forms were received from respondent facilities in the form of data files on diskettes. Data cleaning included a check of the data for self-consistency. For example, if a facility indicated that its classification is 'topping', then it should not have reported any spent FCC catalyst; or if it did not report having an API separator, then there should not be any API separator sludge. The data were also reviewed visually and statistically for outliers. Follow up phone calls resolved apparent discrepancies, such as whether the quantity had been reported in the correct units and, if so, why the amount differed from expected levels.

As with previous surveys, the data from the respondents were extrapolated to nationwide estimates by applying a regression analysis in which throughput capacity is taken as the explanatory variable. For consistency with previous years, the following form of equation was retained.

$$\sqrt{R} = b_0 + b_1 C$$

Where:

R = total residuals managed by a facility (wet tons),
b_0 = the y-intercept of the regression line,
b_1 = the slope of the regression line, and
C = the throughput capacity of the facility (bsd).

The equation developed from the 1995 survey is

$$\sqrt{R} = 31.913 + 7.888 \times 10^{-4} C$$

with an R^2 measure of correlation equal to 0.70, which is an improvement over the correlation measure determined for previous surveys. While the correlation improved and the variance decreased, the percent error increased somewhat (from 5.44% to 7.43%) due to the lower estimated total quantity (3.05 million wet tons rather than 4.80 million wet tons). The statistical analysis is described in more detail in Appendix B.

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Section 2
RESULTS

RESPONSE RATE

The 1995 survey response rate is illustrated by several parameters in the following charts.

Figure 2—Response Rate by Refinery Capacity.

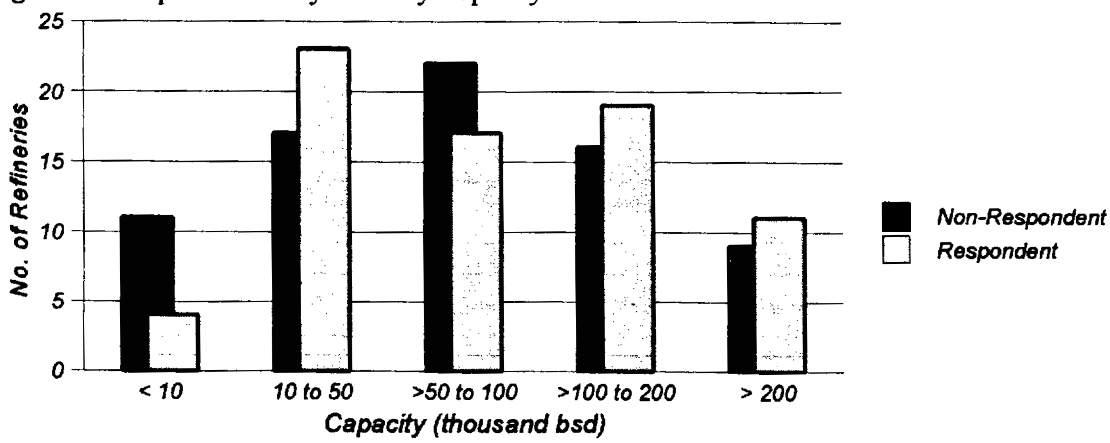

Figure 3—U.S. Department of Energy's Petroleum Administration for Defense (PAD) regions.

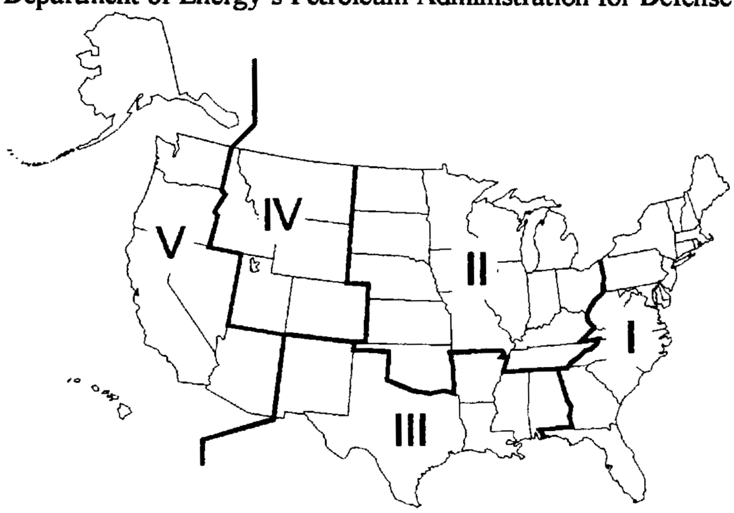

Figure 4—Response Rate by PAD Region.

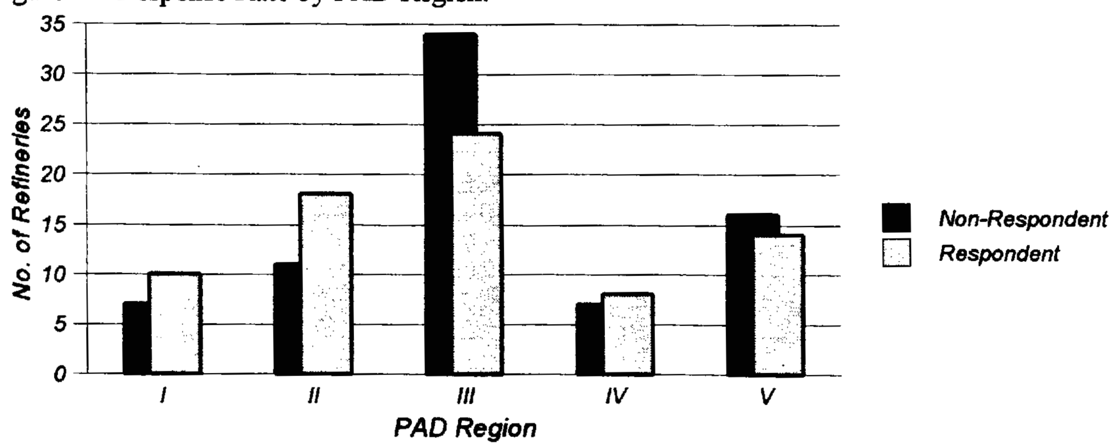

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Figure 5—Response Distribution by Complexity of Facility.

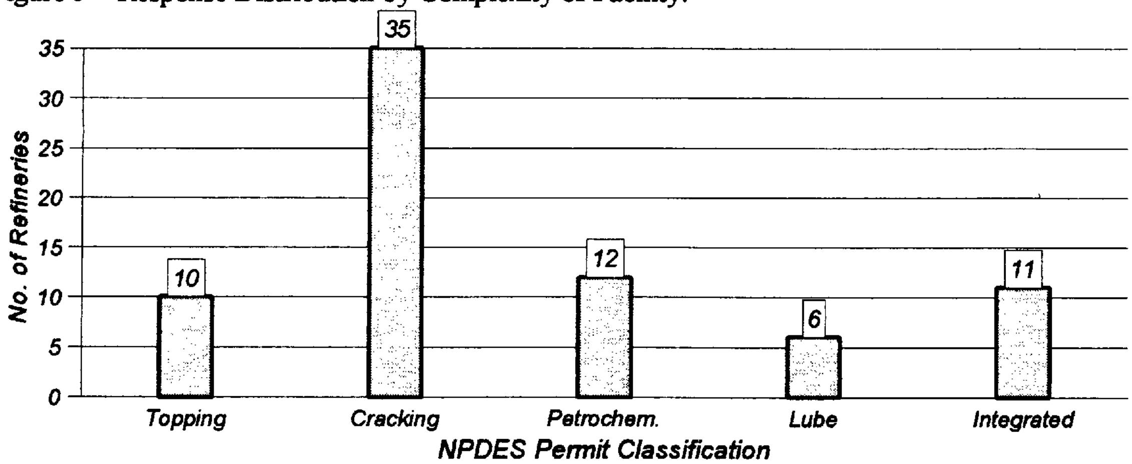


Figure 6—Response Distribution by Age of Facility.

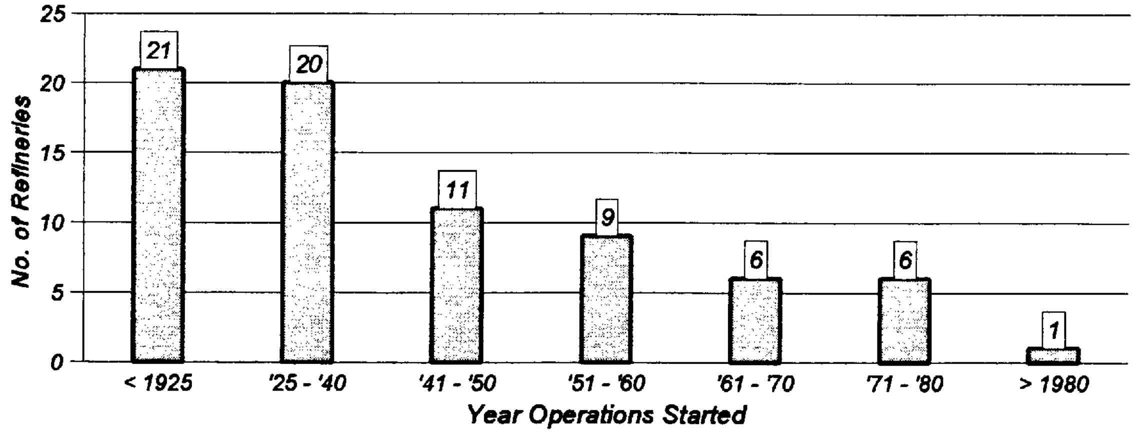
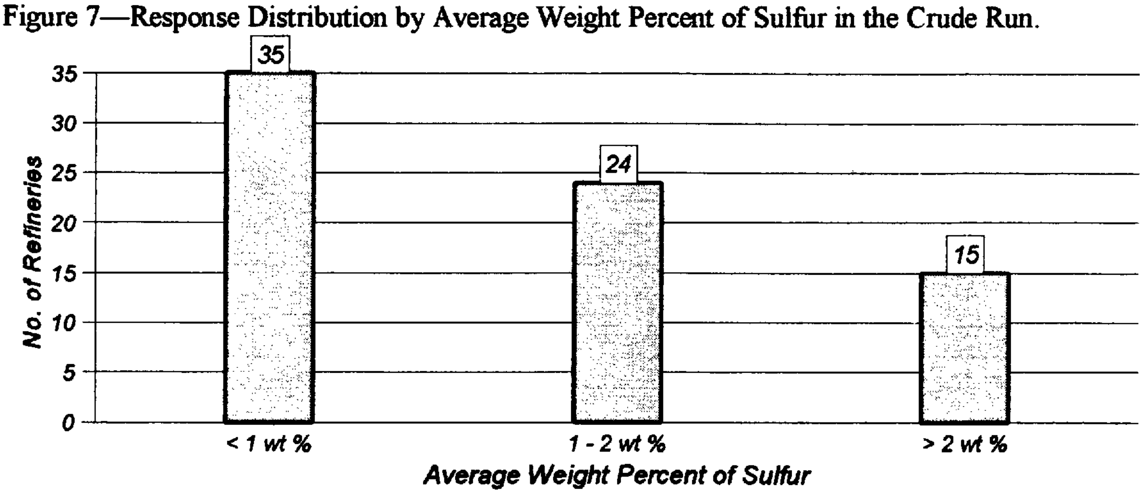


Figure 7—Response Distribution by Average Weight Percent of Sulfur in the Crude Run.



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REPROCESSING OF USED OIL

The 1995 survey added a question concerning the reprocessing of used oil. The question asked whether the refinery had received direct delivery of used oil for reprocessing that was generated by vehicles or equipment at other company-owned or non-company-owned facilities. Only eight of the 74 respondents answered yes, and two of those did not report the amount. One additional facility that responded no, however, did list a quantity. These nine facilities ranged in size from 5,500 to 157,900 bsd, and represented every PAD region except III. The amounts of used oil reprocessed by the seven facilities that reported a quantity varied from 1 wet ton to 14,655 wet tons. The total reported amount was 19,486 wet tons, and the median amount was 42 wet tons.

WASTEWATER TREATMENT FACILITY

Every responding facility indicated that its wastewater is treated prior to discharge. All of the 74 responding facilities reported having primary oil-water separation equipment, with 58 indicating that they use an API Separator. The remaining 16 facilities listed various types of equipment for primary separation, with the most frequent mention being a corrugated plate interceptor. There was no apparent correlation to facility size among those using equipment other than an API Separator, in that their capacities ranged from 5,500 to 290,000 bsd. The distribution of equipment in the wastewater treatment facilities is illustrated by the schematic in Figure 8 on the following page.

Three facilities reported having primary separation only. The remaining respondents (96%) reported some wastewater treatment in addition to primary separation. The equipment for slightly more than half of the wastewater facilities includes primary separation, gas flotation, and activated sludge. The following list summarizes the responses.

Primary separation	100% (typically an API Separator)
Secondary separation	84% (typically some type of gas flotation)
Secondary biological treatment	84% (typically includes activated sludge)
Polishing and/or tertiary treatment	51% (no dominant equipment type)

None of the respondents reported having biological denitrification, and only one facility reported having metals removal in their wastewater plant.

Figure 9 illustrates the type of structures used to hold stormwater and wastewater. The predominant type of structure reported for holding wastewater-only was tanks and for stormwater-only was impoundments. More than half of the respondents (42 out of 74) reported using segregated sewers. Four of the facilities that reported segregated wastewater did not indicate how their stormwater was managed. The other facilities reporting segregated wastewater also listed segregated stormwater, combined sewers, or both–in addition to their segregated wastewater sewer. The reporting of multiple sewers by these facilities resulted in the total number of responses in Figure 9 exceeding 74.

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Figure 8--Wastewater Treatment System Summary. (total number of responses = 74)

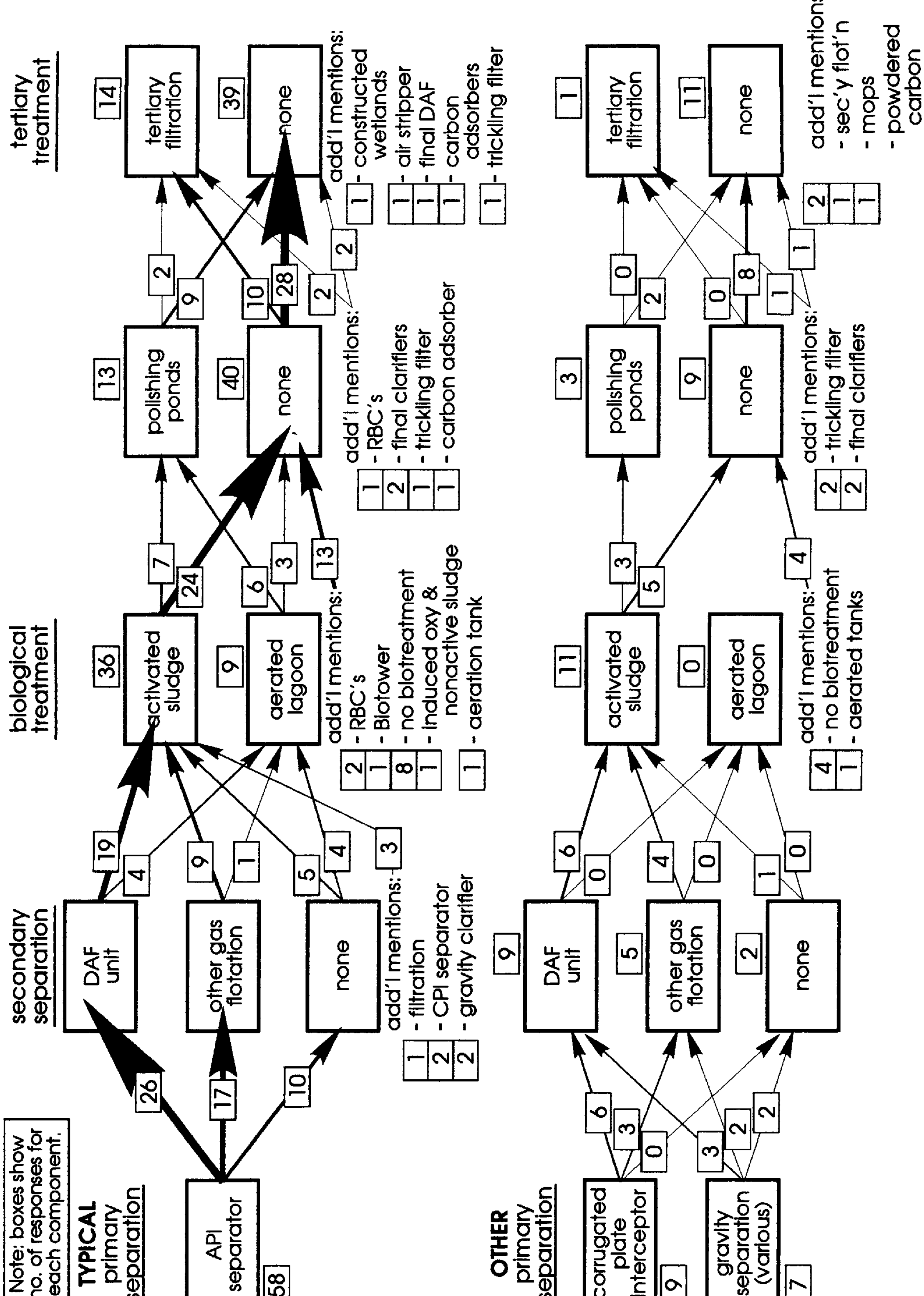

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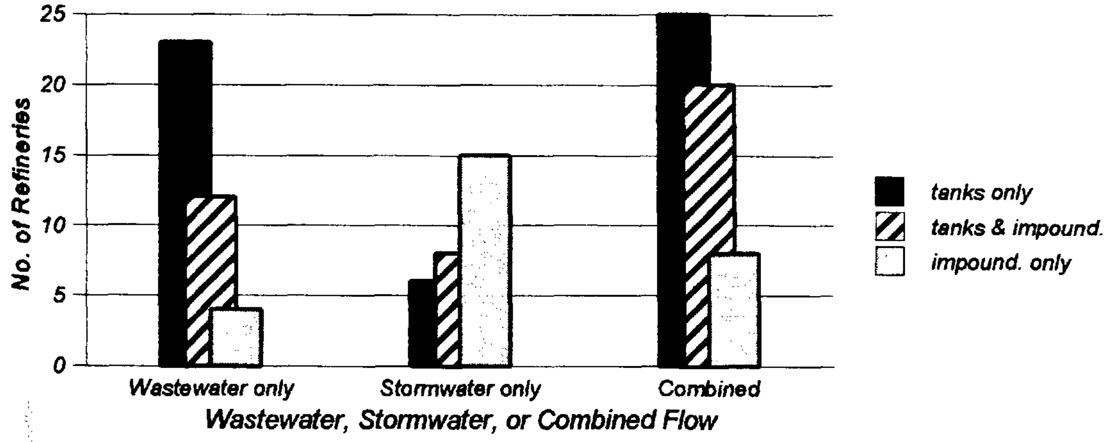
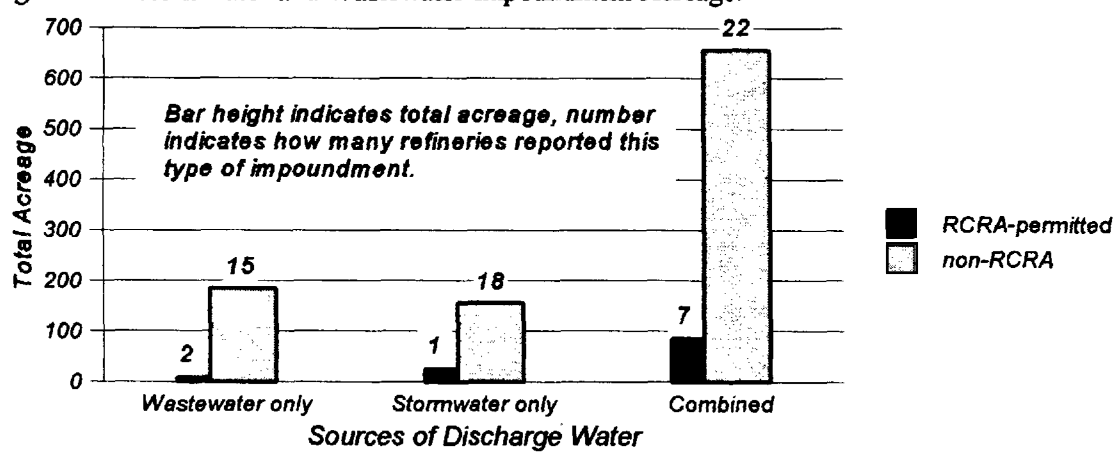
Figure 9—Stormwater and Wastewater Holding Structures.



Most of the facilities that reported using impoundments also reported the estimated acreage, which varied from 0.03 to 350 acres per facility. Figure 10 shows the total acreage having RCRA permits or interim status versus the acreage of impoundments that are not RCRA regulated. The chart also indicates the number of respondents for each category.

Figure 10—Stormwater and Wastewater Impoundment Acreage.



Every responding facility listed the quantity of wastewater discharged daily. The average of the reported daily discharge rates was 2.7 million gallons per day (MGD), and the median rate was 1.6 MGD. One facility indicated that it practices 100% evaporation, and thus is a zero discharge facility. All but one of the remaining respondents gave a breakdown of the sources of their discharge water, with each reporting some contribution from process wastewater. The number of facilities reporting each source of discharge water is shown in Figure 11. Note that most facilities report more than one source of discharge water. Of those listing 'other' sources, most reported the other source to be blowdown water.

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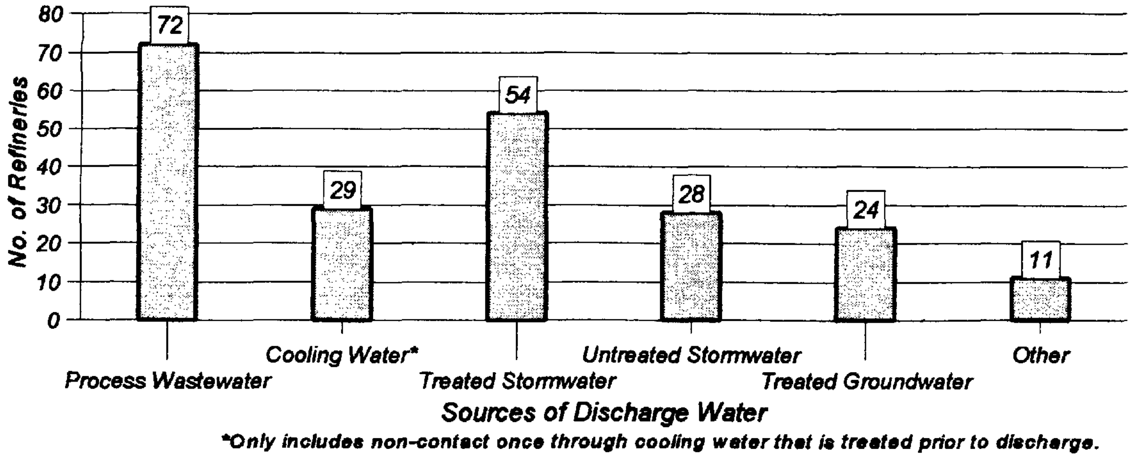
Figure 11—Sources of Discharge Water.



Additional detail on the sources of discharge water is provided in Table 1. In this table, the contribution of each source is shown as a percent of total discharge water, for those facilities reporting that source.

Table 1—Sources of Discharge Water as a Percent of Total.

	No. of Respondents reporting this source	Range	Median	Median Flow (MGD)
Process Wastewater	72	5 – 100 %	76%	1.0
Noncontact Cooling Water*	29	2 – 94 %	22%	0.13
Treated Stormwater	54	1 – 56 %	9%	0.17
Untreated Stormwater	28	1 – 42 %	8%	0.13
Treated Groundwater	24	1 – 80 %	1.7%	0.05
Other	11	1 – 63 %	23%	0.03

* only includes non-contact once through cooling water that is treated prior to discharge.

Levels of eight discharge parameters were requested in the question on effluent quality. The levels are presented as an amount (pounds per year) in Table 2, and as a concentration (pounds per million gallons) in Table 3.

Table 2—Water Quality Discharge Parameters (pounds per year).

	No. of Respondents reporting this parameter	Median
Total Suspended Solids (TSS)	72	66,000 lbs
Biochemical Oxygen Demand (BOD)	68	40,000 lbs
Chemical Oxygen Demand (COD)	60	310,000 lbs
Ammonia	66	9,400 lbs
Oil & Grease	72	17,000 lbs
Chromium	45	29 lbs
Nickel	12	120 lbs
Selenium	19	42 lbs

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Table 3—Water Quality Discharge Parameters (pounds per million gallons of wastewater discharge).

	Median-1995	Median-1994
Total Suspended Solids (TSS)	130 lbs/MG	113 lbs/MG
Biochemical Oxygen Demand (BOD)	77 lbs/MG	54 lbs/MG
Chemical Oxygen Demand (COD)	680 lbs/MG	583 lbs/MG
Ammonia	31 lbs/MG	31 lbs/MG
Oil & Grease	26 lbs/MG	22 lbs/MG
Chromium*	0.08 lbs/MG	*
Nickel*	0.20 lbs/MG	*
Selenium*	0.15 lbs/MG	*

*no data available for 1994.

POLLUTION PREVENTION

The pollution prevention question was simplified in the 1995 survey. Rather than soliciting pollution prevention practices for each residual stream, a single listing was requested for the entire facility. The question asked for a description of those pollution prevention activities undertaken in 1995. Most respondents listed only those projects brought on line in 1995, but it is evident from other portions of the survey that virtually every facility practices certain pollution prevention techniques, such as recycling.

Many of the pollution prevention techniques relate to recognizing that waste streams are often comprised largely of water and dirt which have been contaminated by being combined with process materials. Accordingly, the pollution prevention techniques include:

- reducing the amount of dirt that enters the oily wastewater stream,
- reducing the amount of water that enters the oily wastewater stream,
- dewatering to reduce the volume of oily sludges, and
- minimizing the contamination of dirt by reducing spills and leaks.

In addition to reducing the volume of water and dirt in the wastewater residuals, the industry has continued to implement strategies to better manage the process residuals, including:

- source reduction,
- waste segregation, and
- recycling.

Each of these practices is enhanced by education and training. The specific responses from the 1995 survey are listed in Table 4.

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Table 4—Pollution Prevention Activities.

General Practice	Survey Response
Reduction of dirt to the oily water sewer.	Improved housekeeping. Modified drains and sewers. Cleaned stormwater drains upstream of the oily sewer. Paved areas that drain into the sewer. Resloped and/or lined earthen dikes and dike areas. Erected construction-type filter screens at sewer inlets.
Reduction of water to the oily water sewer.	Segregated cooling tower blowdown from process wastewater. Segregated steam condensate from process wastewater. Constructed curbs and gutters to direct stormwater away from the oily wastewater sewer.
Dewatering of oily sludges.	Installed new dewatering equipment. Replaced existing dewatering equipment. Expanded the use of dewatering equipment.
Reduction of spills and leaks.	Improved housekeeping. Improved or expanded leak inspection programs. Installed gauges to monitor or control leaks. Replaced leaking lines or gaskets. Improved containment of runoff. Installed spill prevention/collection system at the main dock loading facility. Installed double bottoms in storage tanks. Changed from drums to bulk handling of additives.
Source reduction/process modification.	Process modifications to reduce benzene concentration in the wastewater. Process modifications to reduce FCC catalyst carryover. Improved sulfur processing. Improved oil/water separations in the process units. Reduced use of chlorinated cleaning compounds. Closed surface impoundments. Modified amine treating to reduce the generation of spent sulfidic caustic. Replaced sandblasting media with blast media having a lead stabilizer. Improved hydrocyclone separation of 'blackwater' solids to reduce the amount of coke fines entering the sewer. Reduced methyl ethyl ketone (MEK) feed rates to the aeration basins. Improved pH control.

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Table 4—Pollution Prevention Activities (continued).

General Practice	Survey Response
Waste segregation.	Kept nonlisted residuals from combining with listed wastes. Segregated boiler feedwater, steam condensate, and/or blowdown from the oily wastewater sewer to keep solids such as feedwater treatment solids or hardness precipitation from entering the wastewater facility.
Recycling.	Found markets for materials formerly treated or disposed of. Routed oily sludges to the coker. Designed & constructed a patented spent caustic stripper. Installed fuel blending technology. Installed vapor recovery for storage tanks. Filtered and reused cleaning agents. Recycled office paper.
Education and training.	Raised awareness of the facility's pollution prevention practices.
Improved treatment.	Brought on-line a tertiary treatment facility.

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Section 3
RESIDUAL STREAM PROFILES

The U.S. refinery industry managed an estimated 3.05 million wet tons of material from the fourteen residual streams included in the 1995 API Refining Residual Survey. A summary of the total quantity of residuals managed per year is presented in Figure 12. The data for 1987 through 1994 have been adjusted in Figures 12 and 13 by deleting the quantities considered to be recovered oil or water rather than true residuals.

Figure 12—Nationwide Estimate of Residual Quantity per Year: 1987-1995.

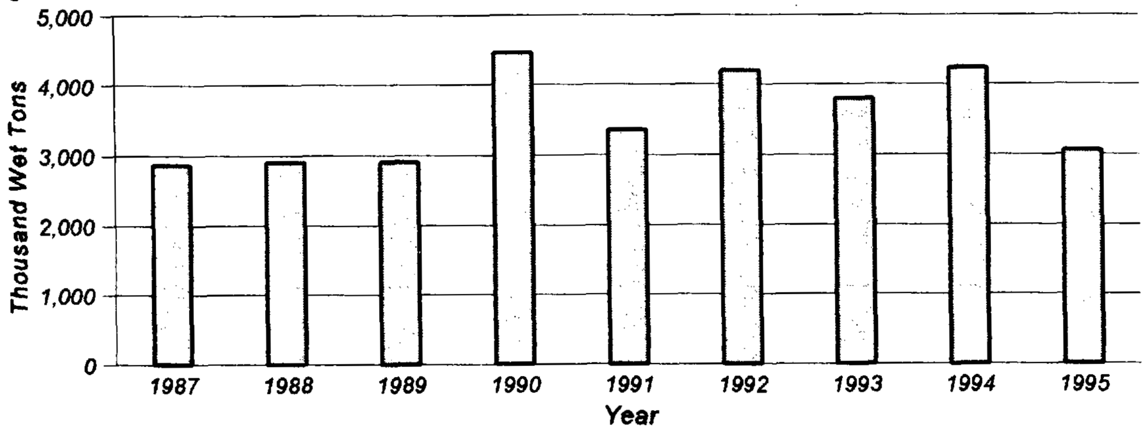
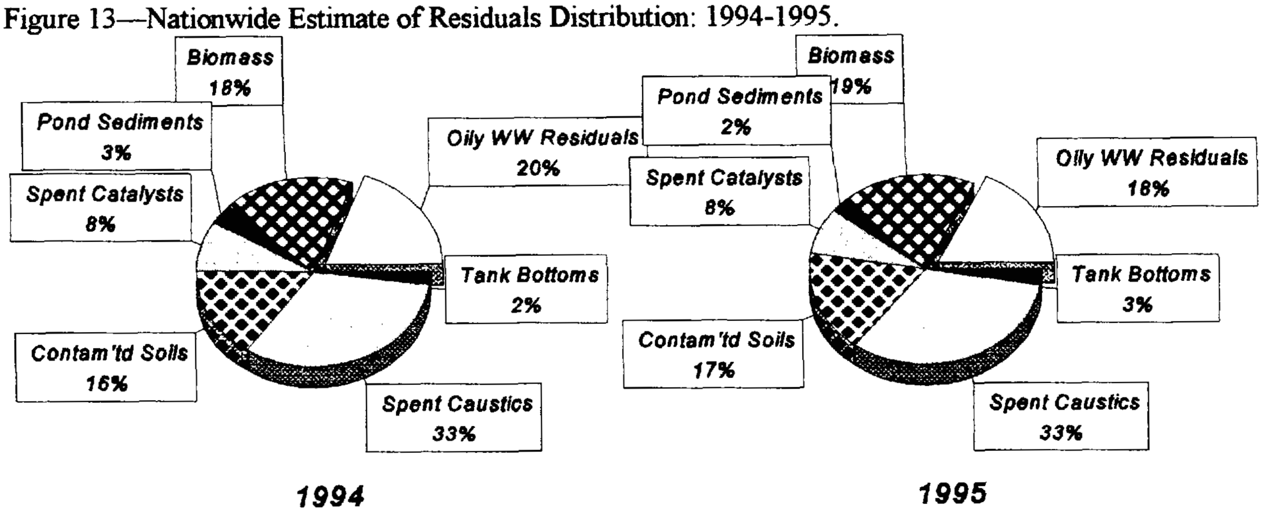


Figure 13 shows the relative contribution of the residual streams, with certain streams grouped together. The FCC catalyst, hydro. catalyst, and other spent catalyst streams are combined into a *spent catalysts* category; and a *spent caustics* category includes spent cresylic caustic, spent naphthenic caustic, and spent sulfidic caustic. The *oily wastewater residuals* (i.e., API separator sludge, DAF float, primary sludges, and slop oil emulsion solids) make up a third grouping. The contribution of each category in 1995 is estimated to be within two percentage points of its contribution to the adjusted 1994 data.

Figure 13—Nationwide Estimate of Residuals Distribution: 1994-1995.



The remainder of this section presents detailed information for the individual streams, with the streams arranged in alphabetical order. The data for this section are summarized in the tables of Appendix C.

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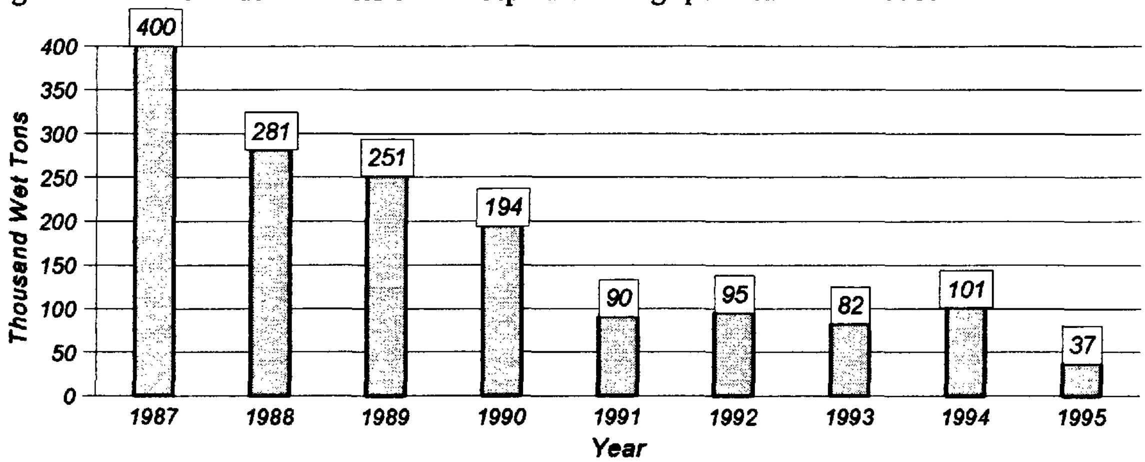
API SEPARATOR SLUDGE[1]

The U.S. petroleum refining industry managed an estimated 37 thousand wet tons of API Separator Sludge in 1995, which was a 63% reduction from 1994. A summary of the quantity of API Separator Sludge managed per year is presented in Figure 14. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

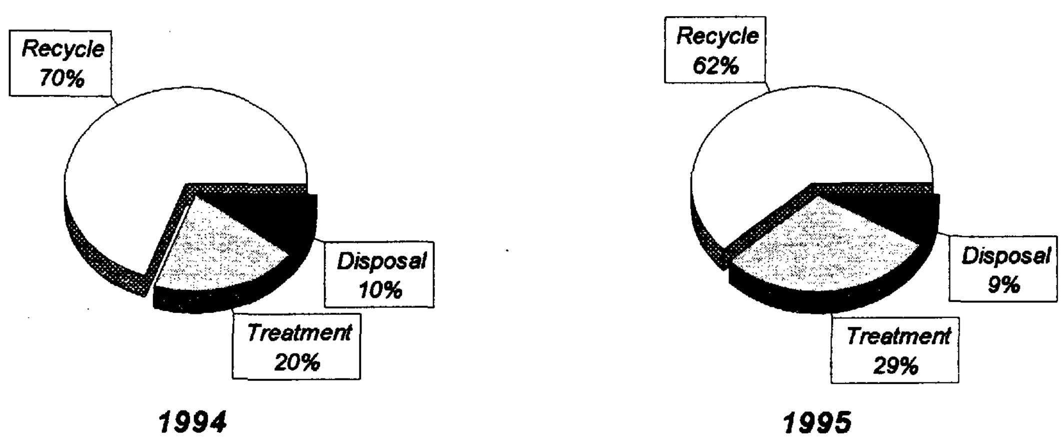
Figure 14—Nationwide Estimates of API Separator Sludge per Year: 1987-1995.



Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantities of these oily wastewater streams are summarized in Figure 85, which shows a decrease from 833 thousand wet tons in 1994 to 554 thousand wet tons in 1995, a reduction of 33%.

The portion of the API Separator Sludge stream that is managed by each management practice is shown in Figure 15 for 1994 and 1995. Recognizing only the actual residual stream, and not recovered oil or water, has shown recycling to be the most common management practice.

Figure 15—Nationwide Estimates of API Separator Sludge by Management Practice: 1994-1995.



[1]Recall that this report uses labels such as API Separator Sludge in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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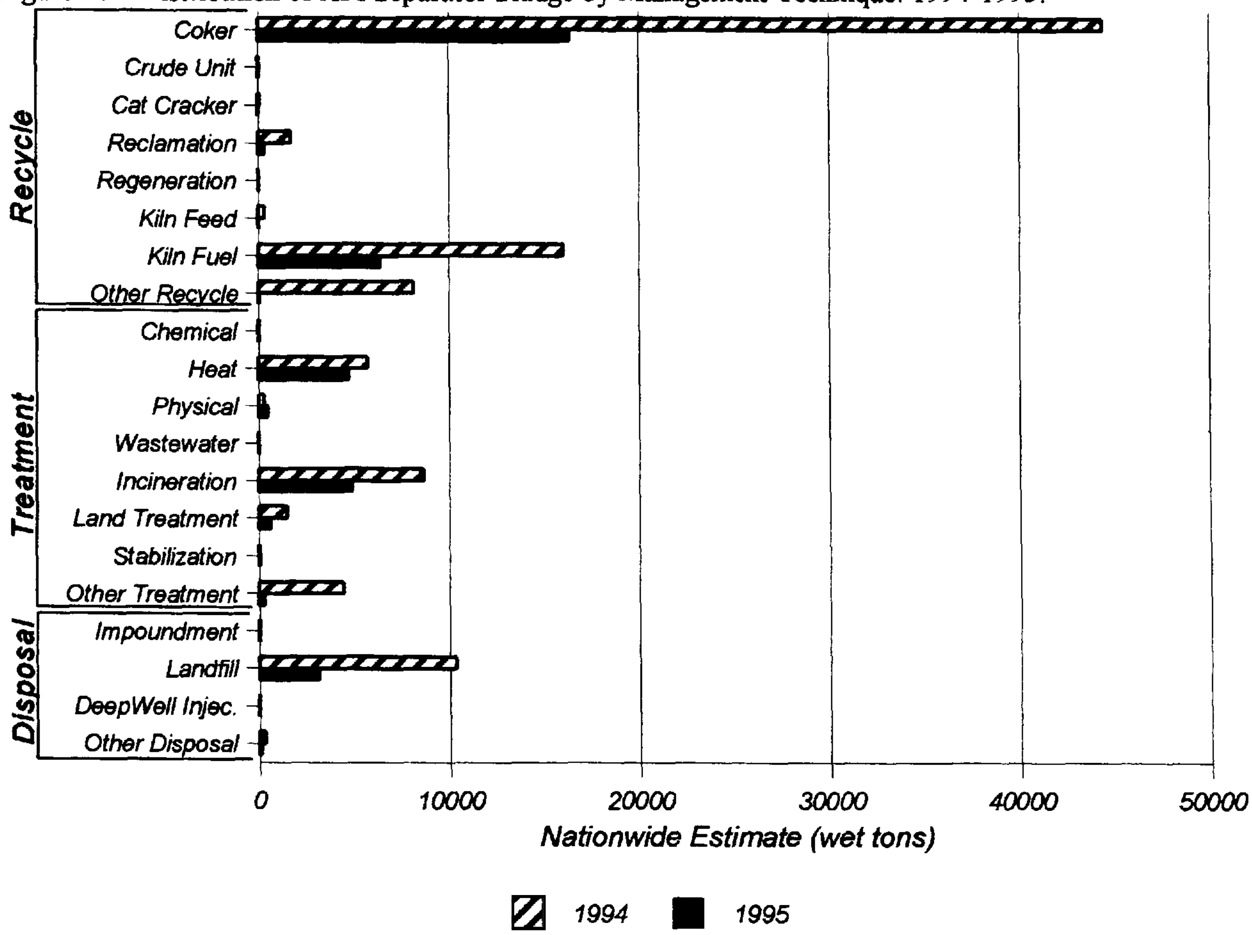
Figure 16 shows the API Separator Sludge distribution by management technique for 1994 and 1995. The quantities shown for recycling to the *crude unit* and for *wastewater* treatment have gone to zero, in that recovered oil and water from dewatering operations are not truly residuals and are no longer included. The *kiln feedstock* quantity shown in 1994 has been eliminated in 1995. The 1994 listing may have been in error, in that API Separator Sludge is typically used as fuel when sent to a cement kiln.

Figure 16—Distribution of API Separator Sludge by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: none.

Other Treatment: one facility uses a proprietary biological process to treat oily sludges.

Other Disposal: one facility sends oily sludges to a treatment, storage, and disposal facility (T.S.D.F.) for disposal.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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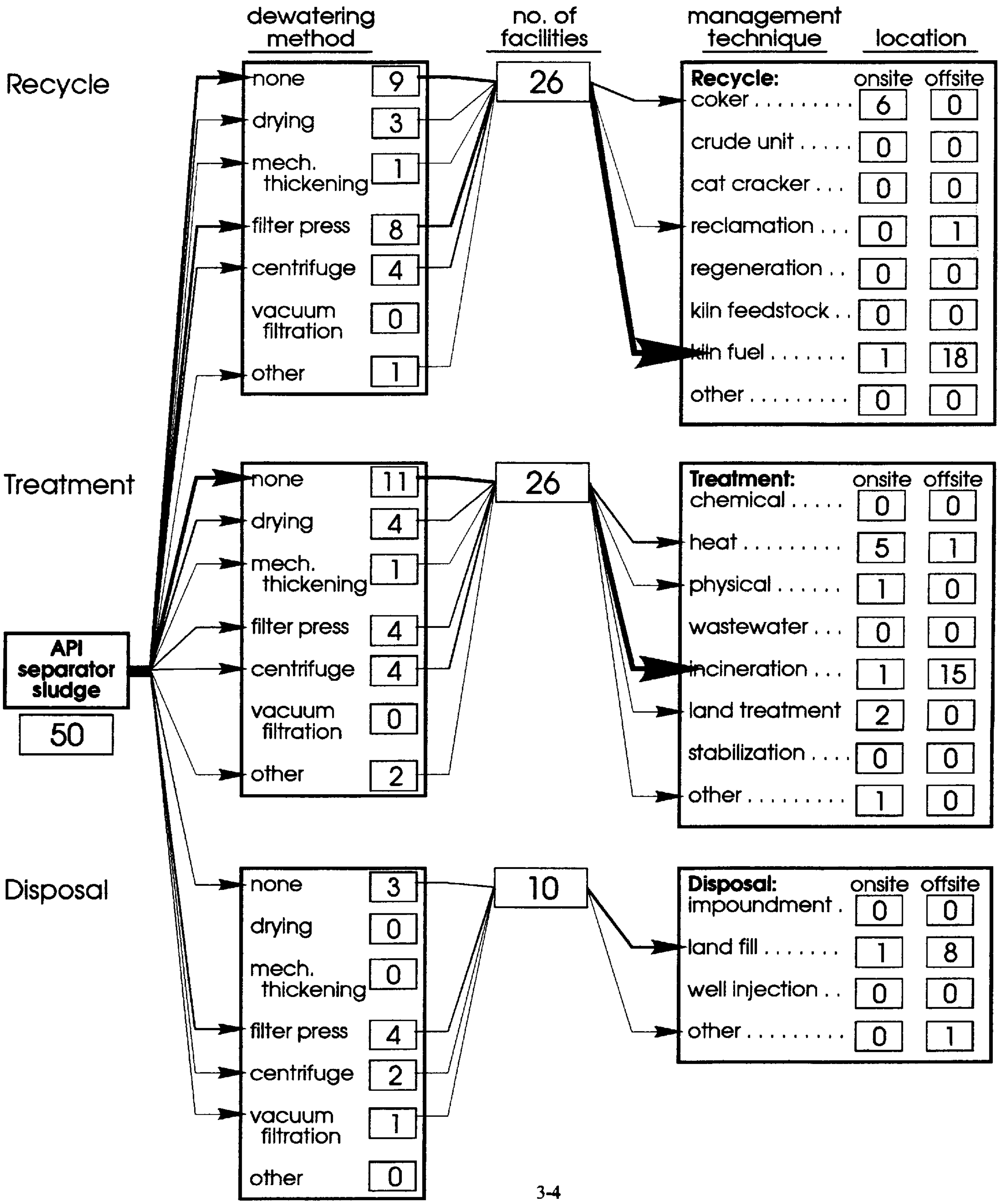
Figure 17 - API Separator Sludge Summary: 1995

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



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The following three graphs summarize the cost data reported for API Separator Sludge.

Figure 18—Onsite Management Cost for API Separator Sludge: 1995

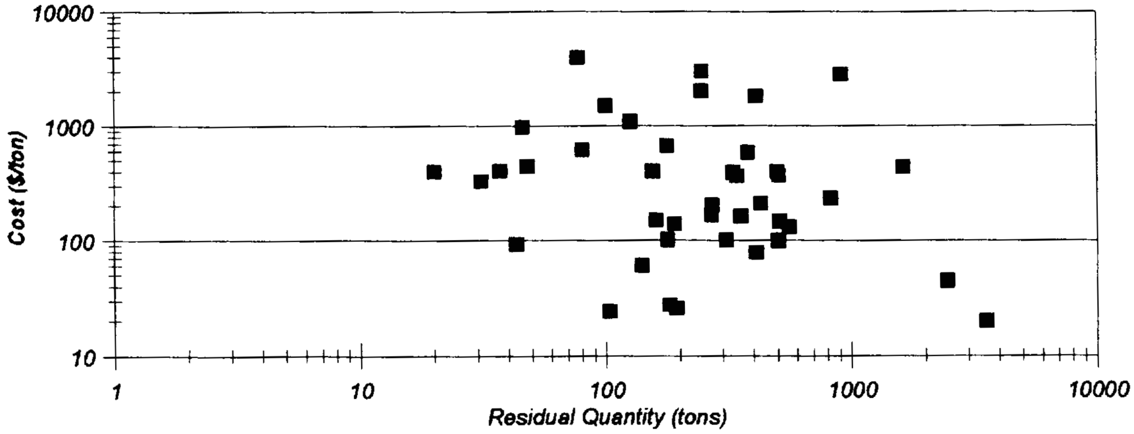


Figure 19—Offsite Management Cost for API Separator Sludge: 1995

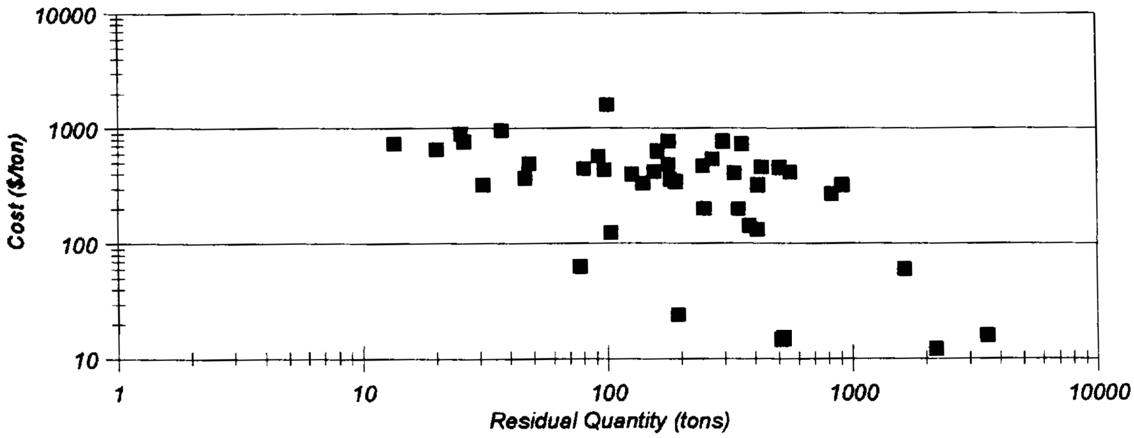
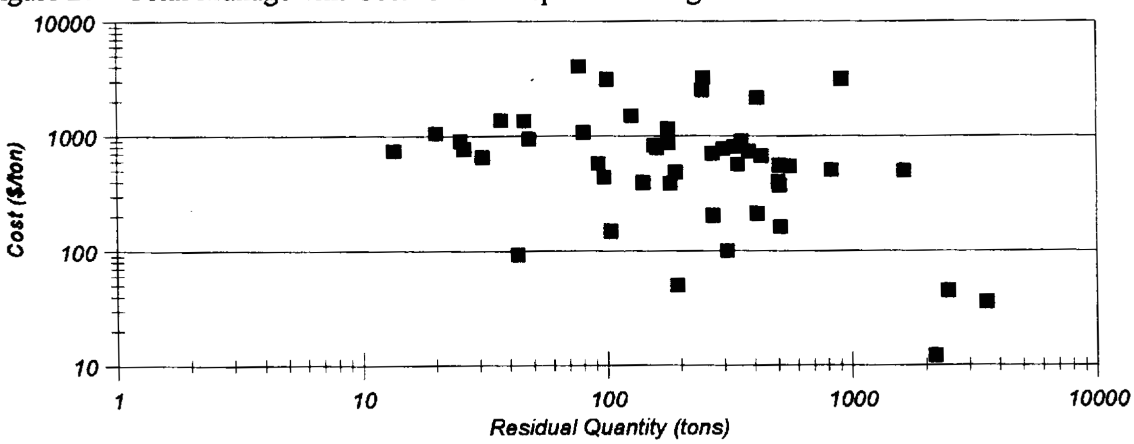


Figure 20—Total Management Cost for API Separator Sludge: 1995



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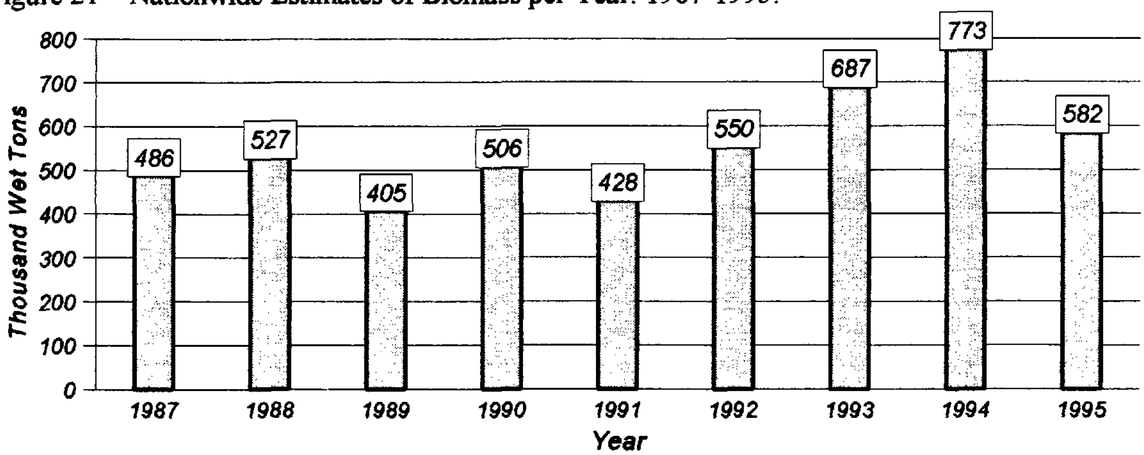
BIOMASS[2]

The U.S. petroleum refining industry managed an estimated 582 thousand wet tons of Biomass in 1995, which was a 25% reduction from 1994. A summary of the quantity of Biomass managed per year is presented in Figure 21. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

Figure 21—Nationwide Estimates of Biomass per Year: 1987-1995.



The portion of the Biomass stream that is managed by each management practice is shown in Figure 22 for 1994 and 1995. Recognizing only the actual residual stream, and not recovered water, treatment continues to be the most common practice.

Figure 22—Nationwide Estimates of Biomass by Management Practice: 1994-1995.

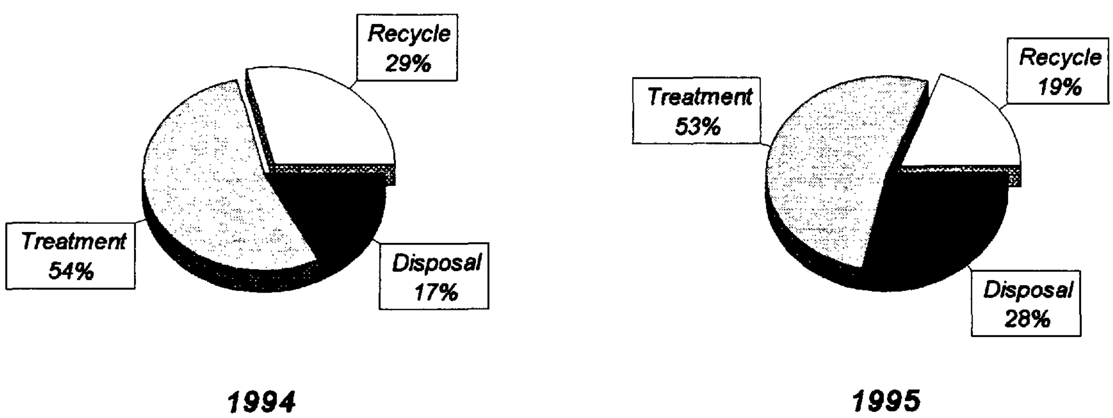


Figure 23 shows the Biomass distribution by management technique for 1994 and 1995. The quantity shown for *wastewater* treatment has gone to zero, in that recovered water from dewatering operations is not truly a residual and is no longer included.

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[2]Recall that this report uses labels such as Biomass in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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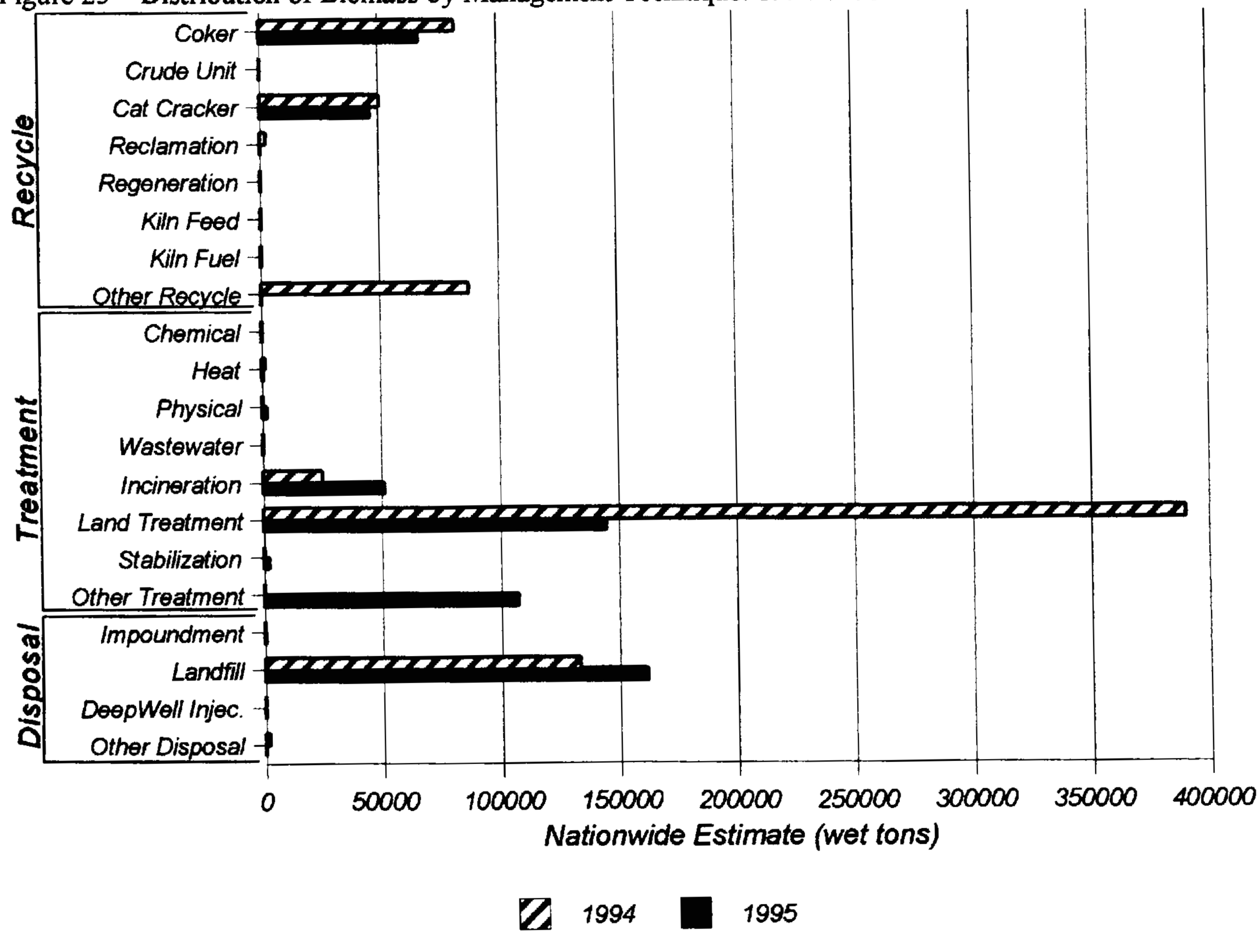
Figure 23—Distribution of Biomass by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: none.

Other Treatment: one facility treats biomass in a sludge digester.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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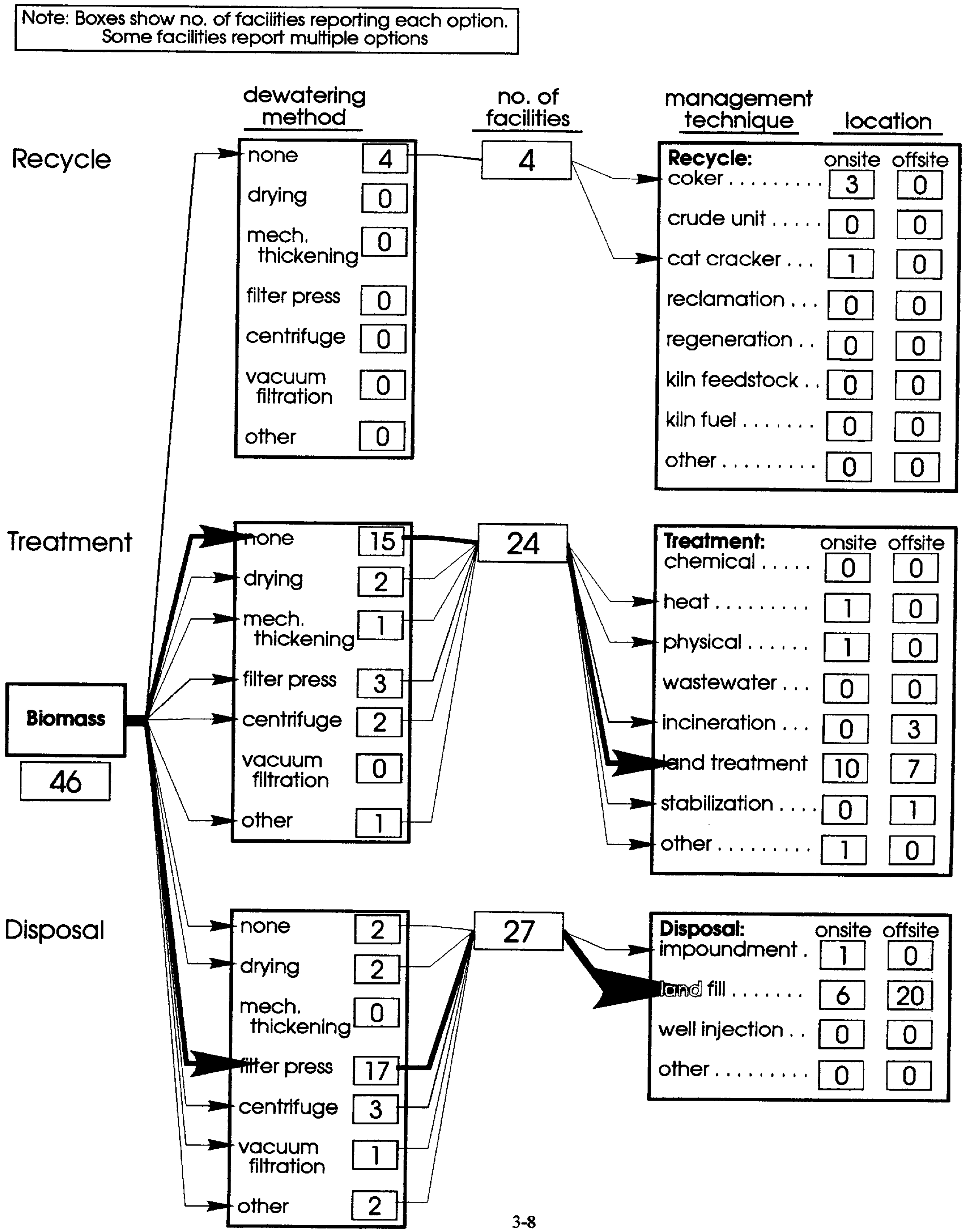
Figure 24 - Biomass Summary: 1995



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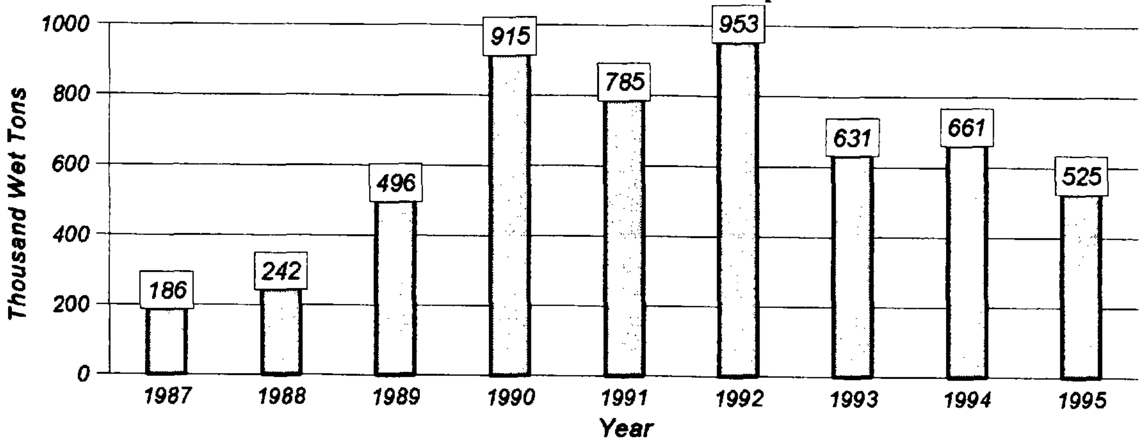
CONTAMINATED SOILS & SOLIDS[3]

The U.S. petroleum refining industry managed an estimated 525 thousand wet tons of Contaminated Soils & Solids in 1995, which was a 21% reduction from 1994. A summary of the quantity of Contaminated Soils & Solids managed per year is presented in Figure 25.

Figure 25—Nationwide Estimates of Contaminated Soils & Solids per Year: 1987-1995.



The portion of the Contaminated Soils & Solids stream that is managed by each management practice is shown in Figure 26 for 1994 and 1995. While the portion of this stream that was treated increased significantly, disposal continues to be the most common practice.

Figure 26—Nationwide Estimates of Contaminated Soils & Solids by Management Practice: 1994-1995.

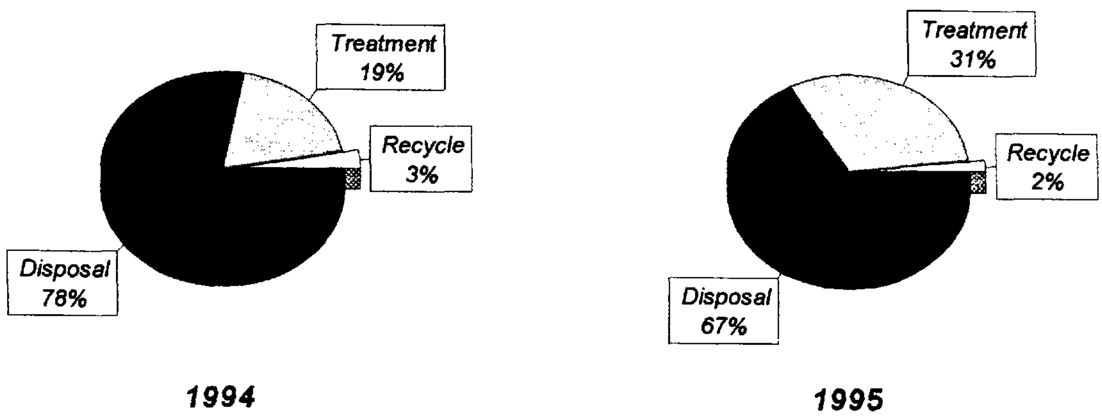


Figure 27 shows the Contaminated Soils & Solids distribution by management technique for 1994 and 1995. The quantity disposed of by *landfilling* decreased, while the use of *land treatment* increased. The largest percent change is the increase in the quantity treated by *heat*. Material listed as treated by *heat* was typically treated by thermal desorption and then reused.

[3]Recall that this report uses labels such as Contaminated Soils & Solids in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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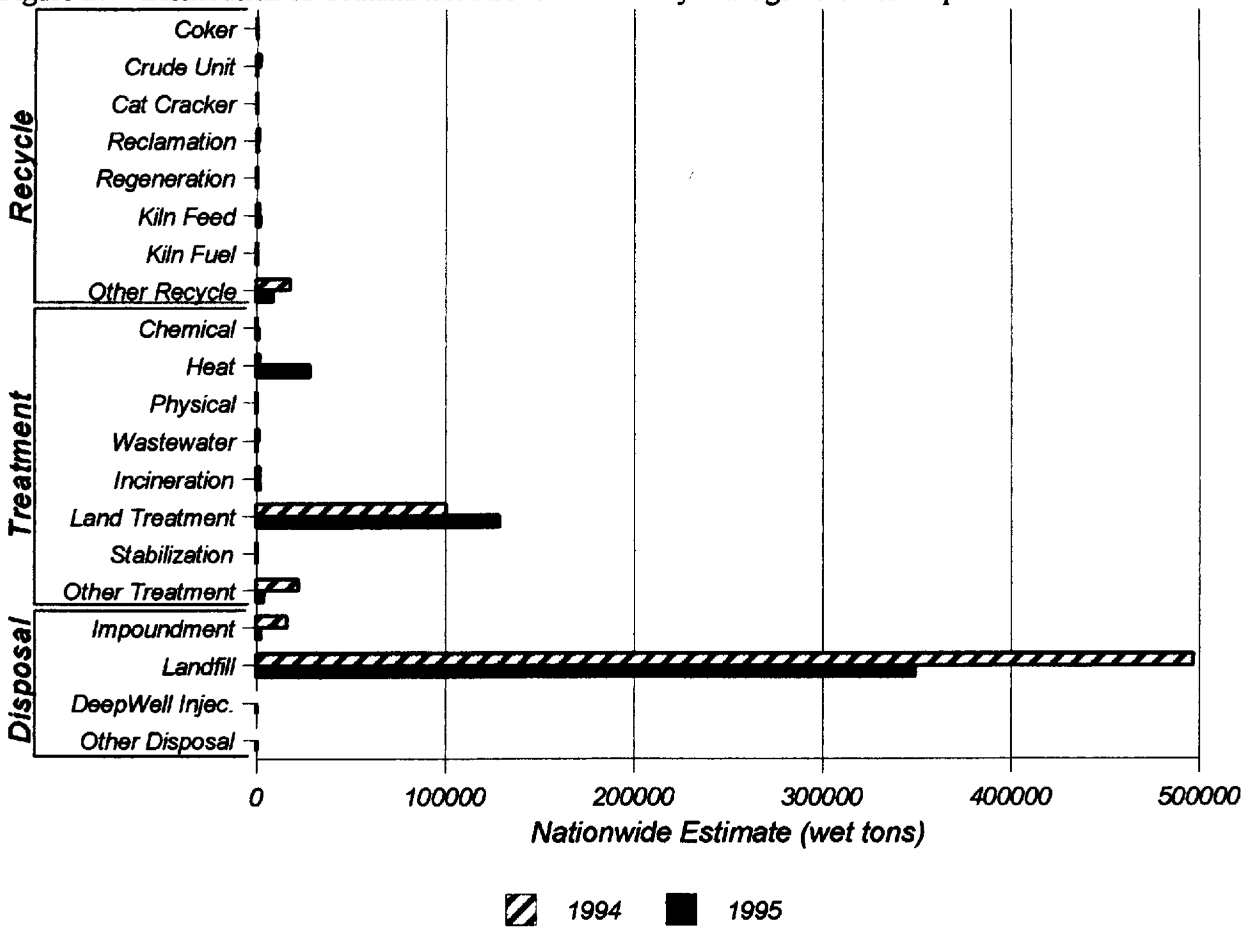
Figure 27—Distribution of Contaminated Soils & Solids by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: three facilities listed reusing contaminated soil as road, dike, or cover material; without requiring any treatment of the contaminated soil.

Other Treatment: two facilities listed bacterial or microbiological treatment of contaminated soil.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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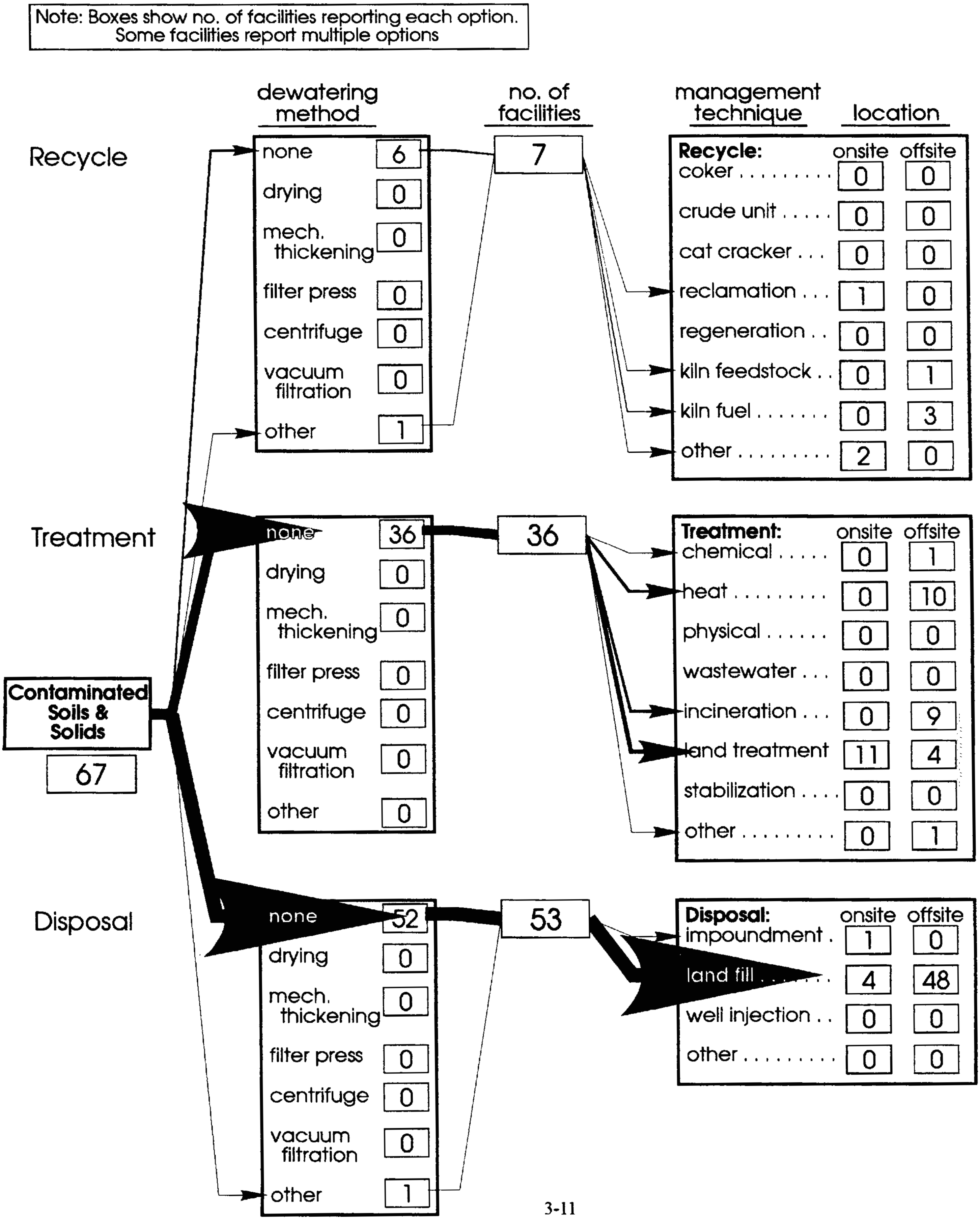
Figure 28 - Contaminated Soils & Solids Summary: 1995



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The following three graphs summarize the cost data reported for Contaminated Soils and Solids.

Figure 29—Onsite Management Cost for Contaminated Soils and Solids: 1995

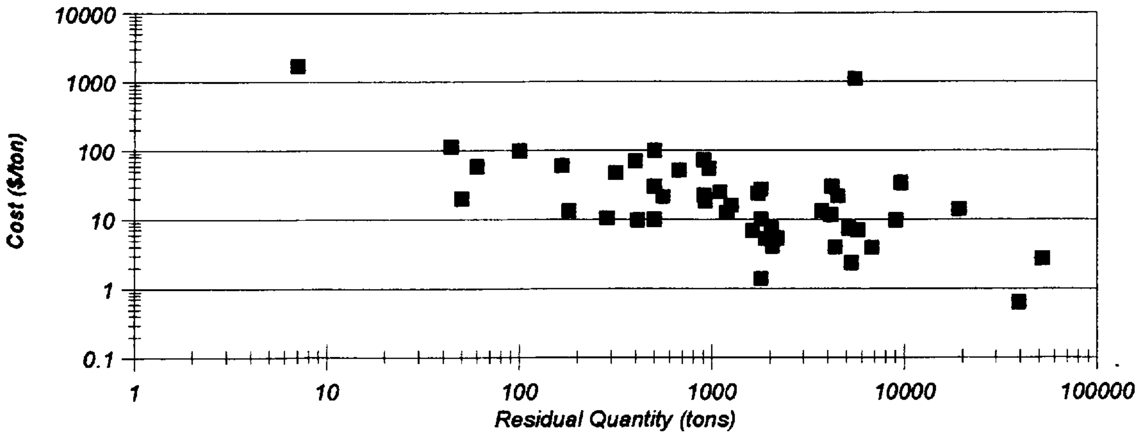


Figure 30—Offsite Management Cost for Contaminated Soils and Solids: 1995

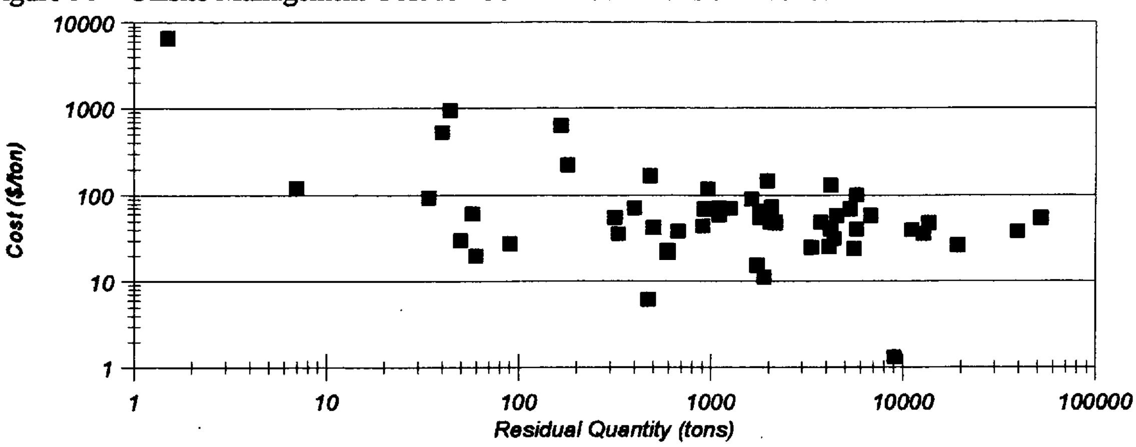
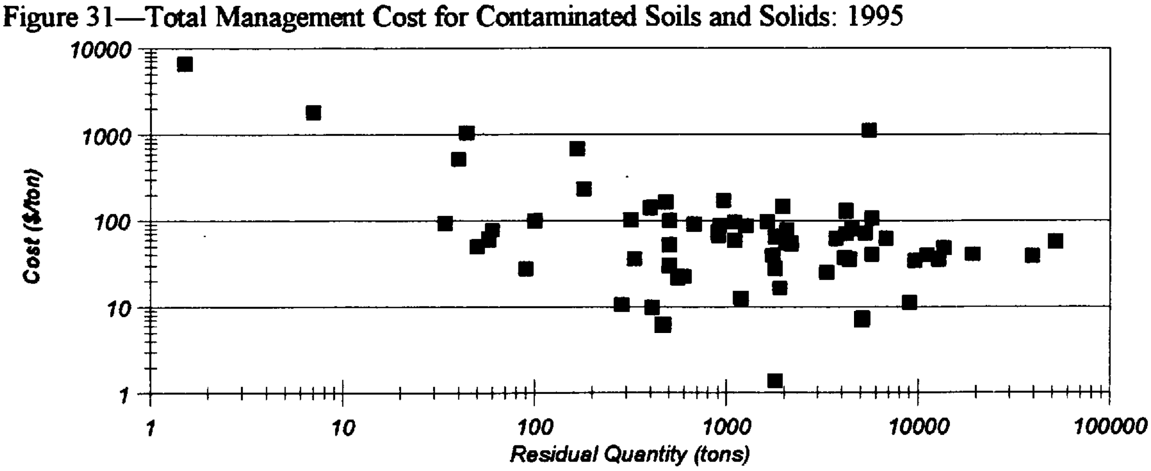


Figure 31—Total Management Cost for Contaminated Soils and Solids: 1995



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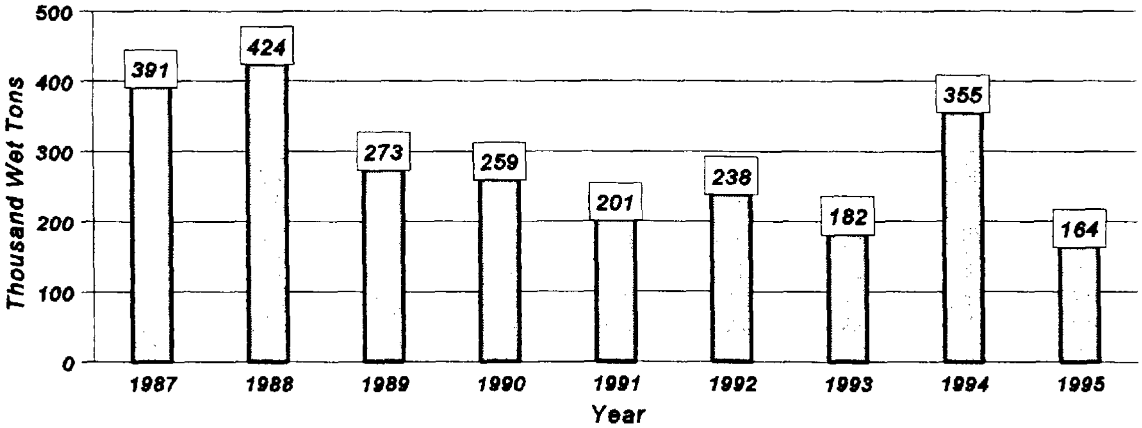
DAF FLOAT[4]

The U.S. petroleum refining industry managed an estimated 164 thousand wet tons of Dissolved Air Flotation (DAF) Float in 1995, which was a 54% reduction from 1994. A summary of the quantity of DAF Float managed per year is presented in Figure 32. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered water rather than true residuals.

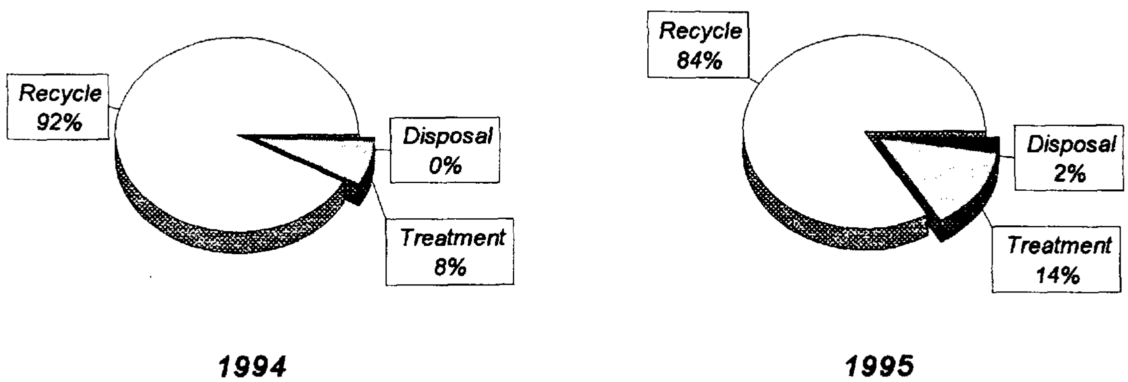
Figure 32—Nationwide Estimates of DAF Float per Year: 1987-1995.



Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantities of these oily wastewater streams are summarized in Figure 85, which shows a decrease from 833 thousand wet tons in 1994 to 554 thousand wet tons in 1995, a reduction of 33%.

The portion of the DAF Float stream that is managed by each management practice is shown in Figure 33 for 1994 and 1995. Recognizing only the actual residual stream, and not recovered oil or water, recycling continues to be the most common practice.

Figure 33—Nationwide Estimates of DAF Float by Management Practice: 1994-1995.



[4]Recall that this report uses labels such as DAF Float in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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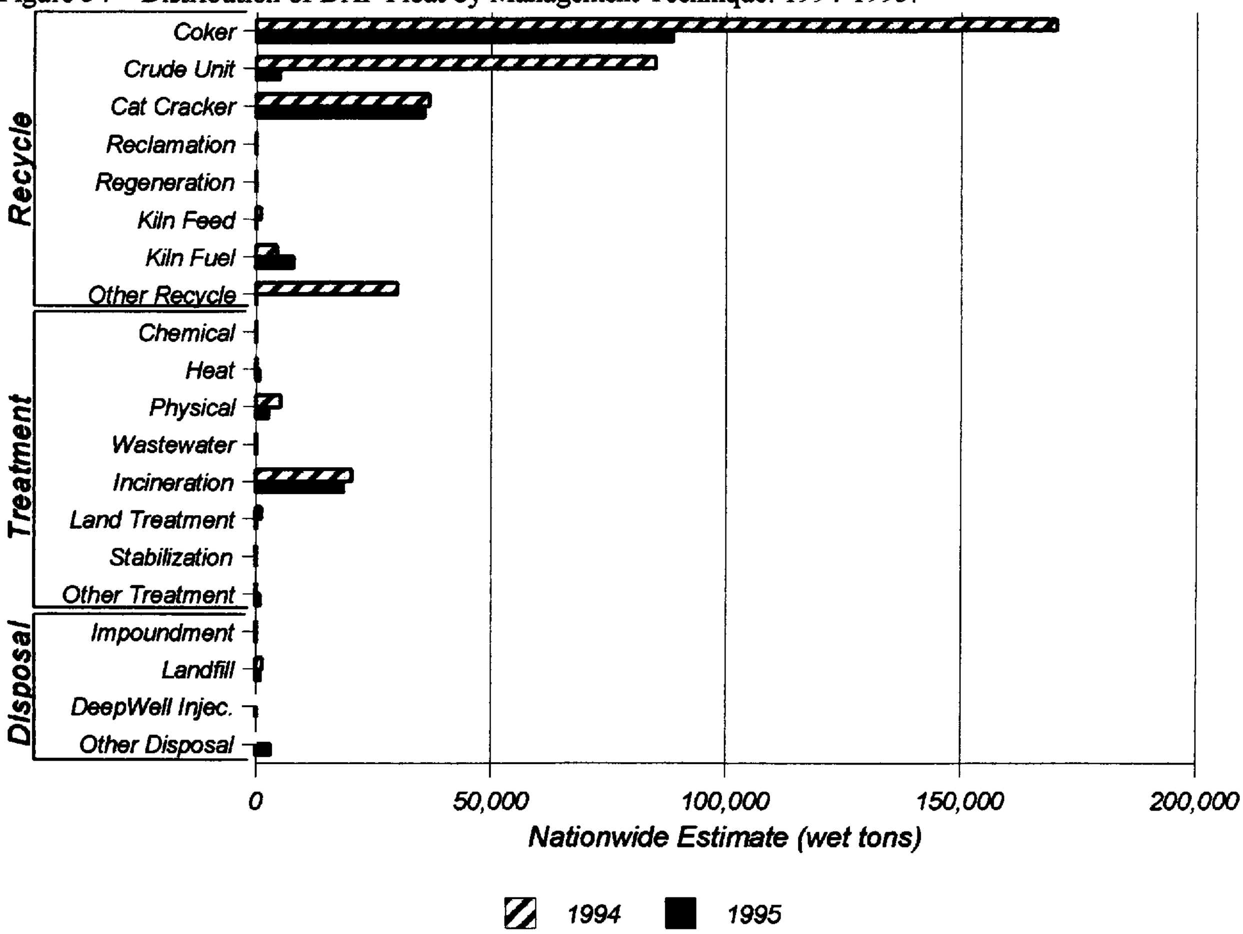
Figure 34 shows the DAF Float distribution by management technique for 1994 and 1995. The quantities shown for recycling to the *crude unit* and for *wastewater* treatment have been nearly eliminated, in that recovered oil and water from dewatering operations are not truly residuals and are no longer included. The *kiln feedstock* quantity shown in 1994 has been eliminated in 1995. The 1994 listing may have been in error, in that DAF Float is typically used as fuel when sent to a cement kiln.

Figure 34—Distribution of DAF Float by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: none.

Other Treatment: one facility uses a proprietary biological process to treat oily sludges.

Other Disposal: one facility sends oily sludges to a T.S.D.F. facility for disposal.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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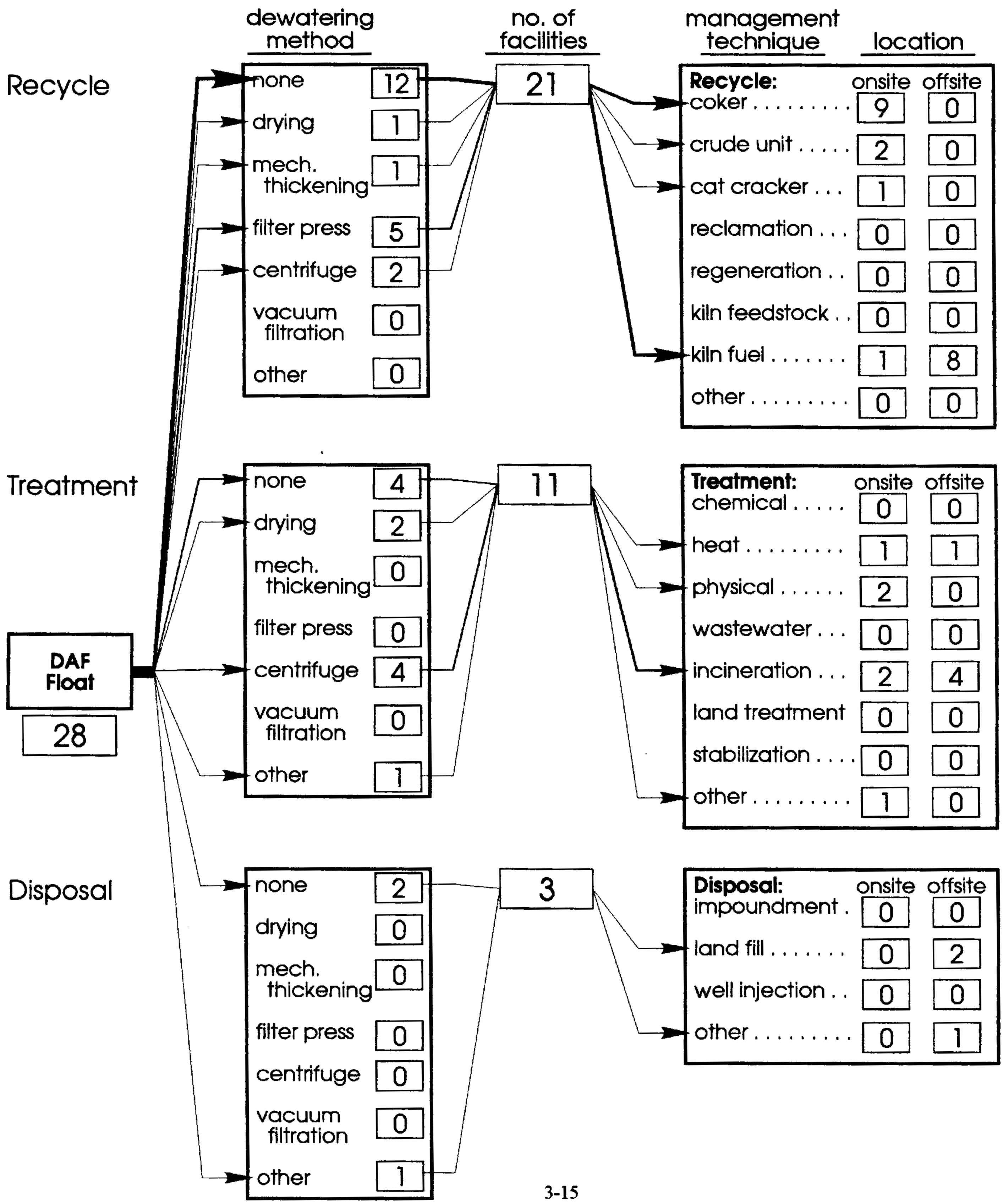
Figure 35 - DAF Float Summary: 1995

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



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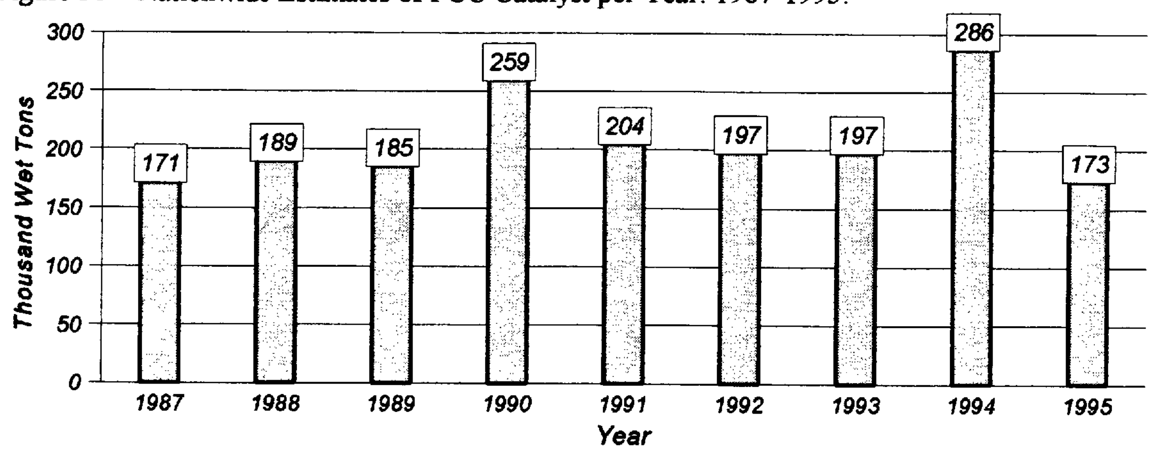
FCC CATALYST[5]

The U.S. petroleum refining industry managed an estimated 173 thousand wet tons of Fluidized-bed Catalytic Cracking (FCC) Catalyst in 1995, which was a 40% reduction from 1994. A summary of the quantity of FCC Catalyst managed per year is presented in Figure 36.

Figure 36—Nationwide Estimates of FCC Catalyst per Year: 1987-1995.



The portion of the FCC Catalyst stream that is managed by each management practice is shown in Figure 37 for 1994 and 1995. Disposal continues to be the most common practice.

Figure 37—Nationwide Estimates of FCC Catalyst by Management Practice: 1994-1995.

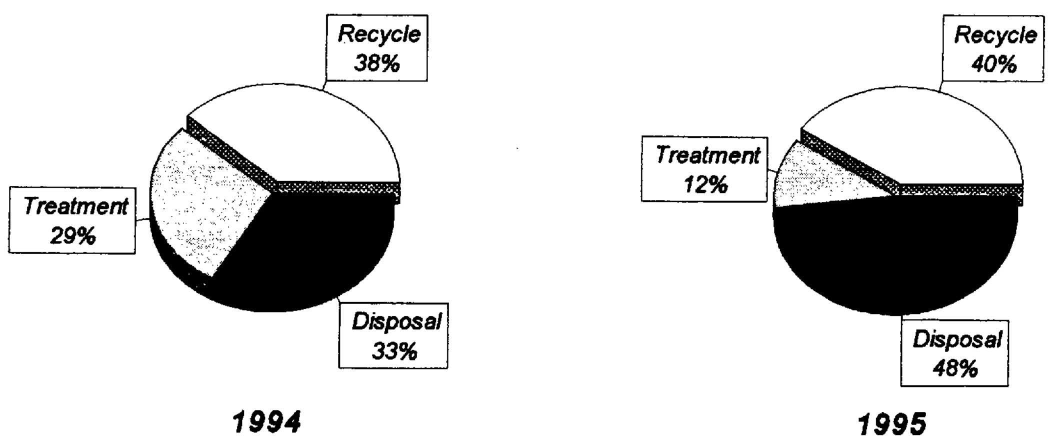


Figure 38 shows the FCC Catalyst distribution by management technique for 1994 and 1995. The *kiln fuel* quantity shown in 1994 has been eliminated in 1995. The 1994 listing may have been in error, in that FCC Catalyst is typically used as feedstock when sent to a cement kiln.

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[5]Recall that this report uses labels such as FCC Catalyst in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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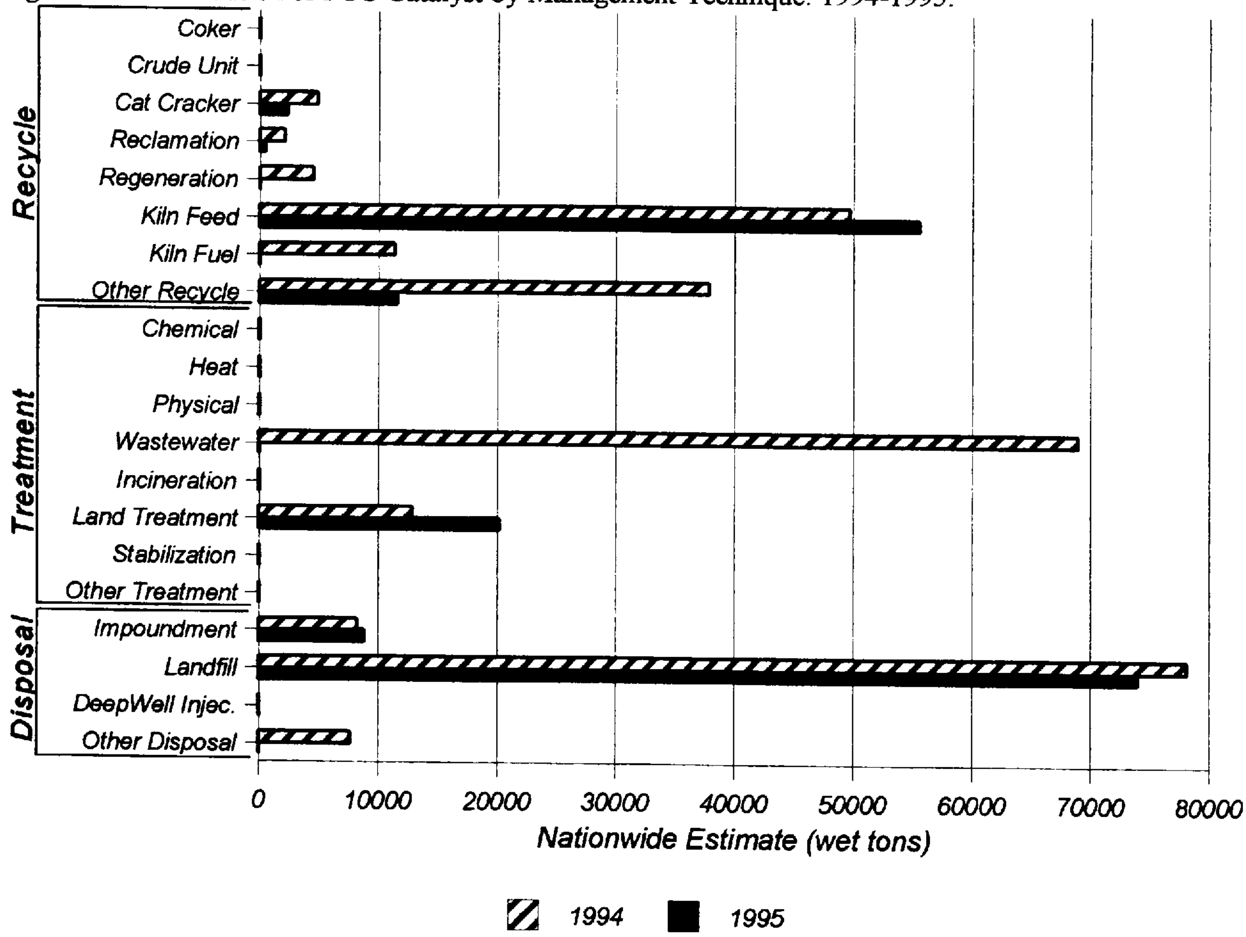
Figure 38—Distribution of FCC Catalyst by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: one facility recycles onsite by cascading the FCC catalyst from an FCC unit to a resid catalytic cracking unit (RCC) which can use lower quality catalyst.

Five facilities listed offsite recycling other than the standard categories. Two of these listed offsite sale without a known end use, another indicated that the end use was brick manufacturing, another indicated that it was used at a landfill to solidify other wastes, and the other facility indicated that the spent FCC catalyst is sold to a broker to be reused as startup catalyst.

Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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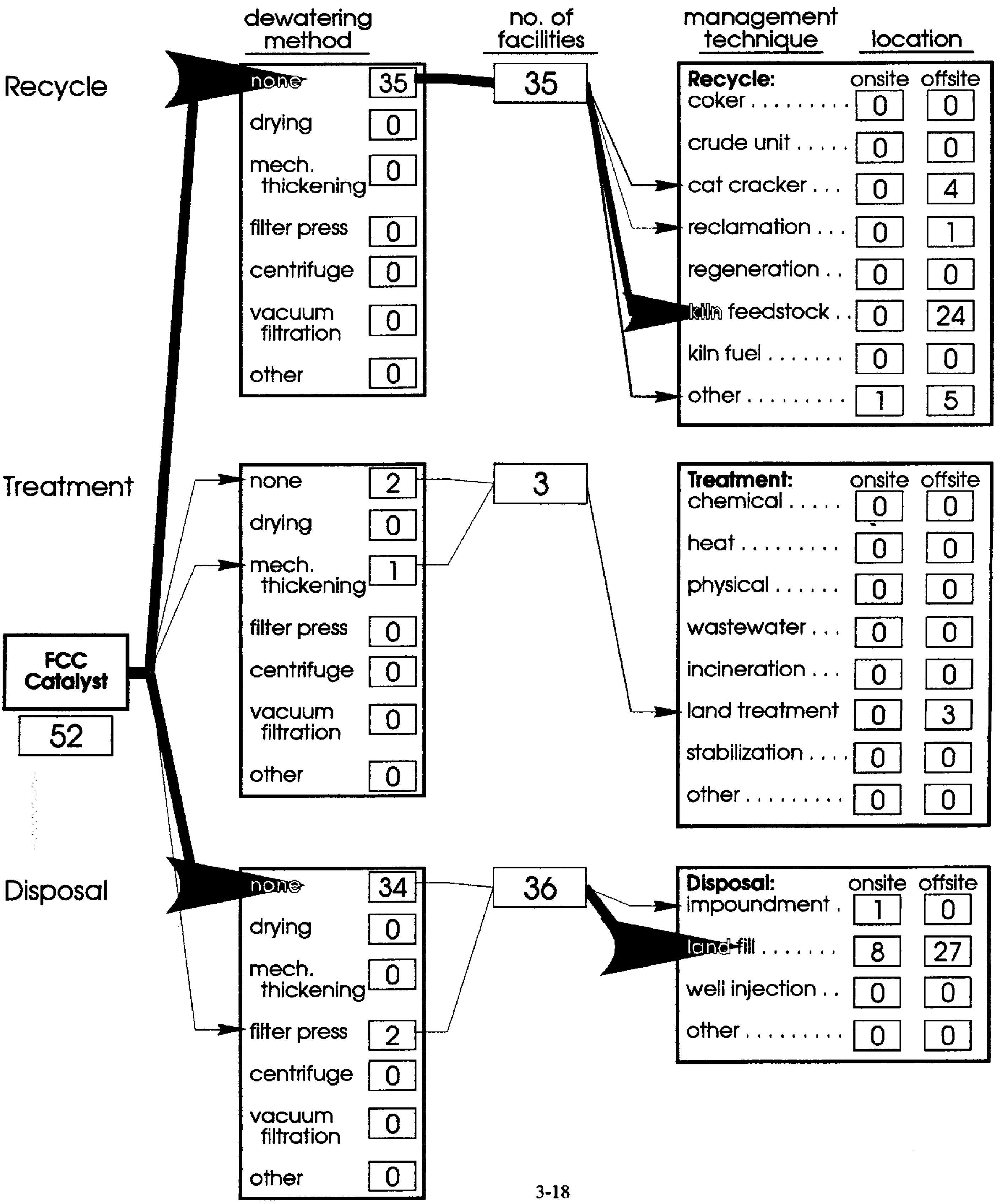
Figure 39 - FCC Catalyst Summary: 1995

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



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The following three graphs summarize the cost data reported for FCC Catalyst.

Figure 40—Onsite Management Cost for FCC Catalyst: 1995

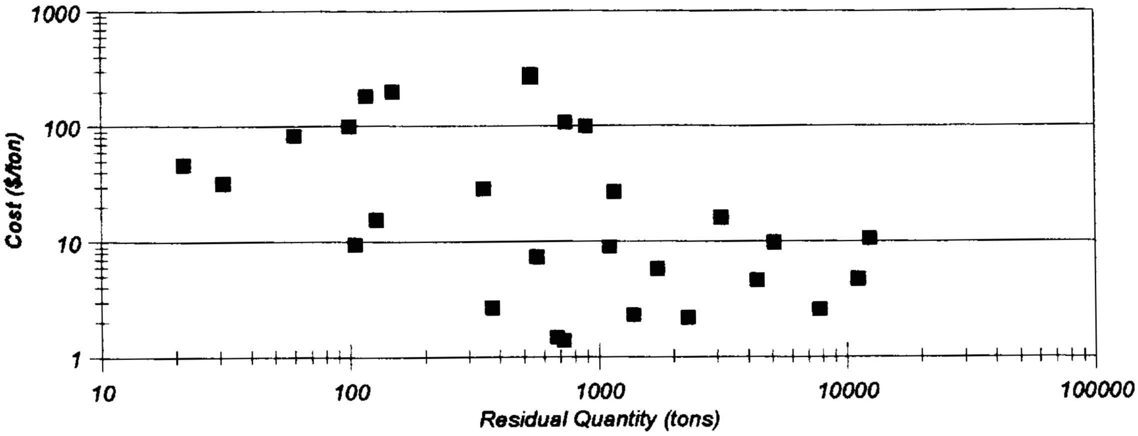


Figure 41—Offsite Management Cost for FCC Catalyst: 1995

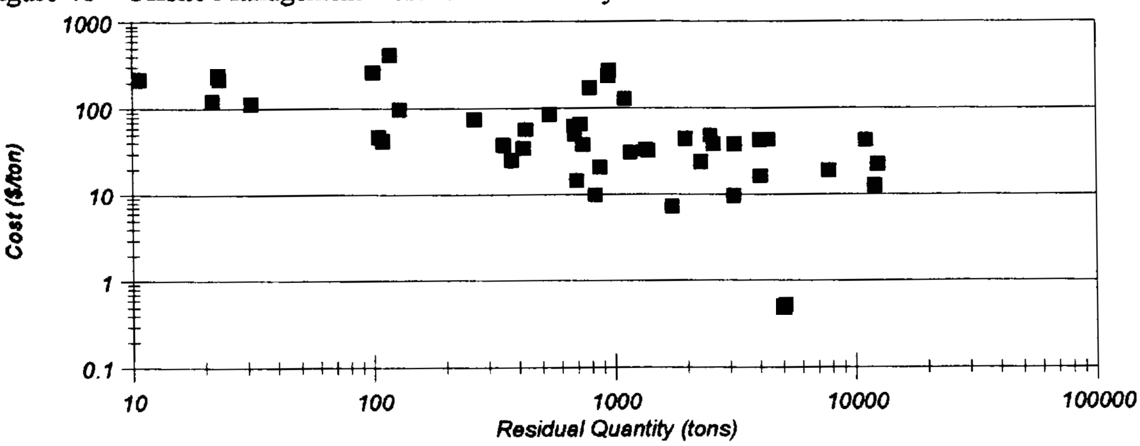
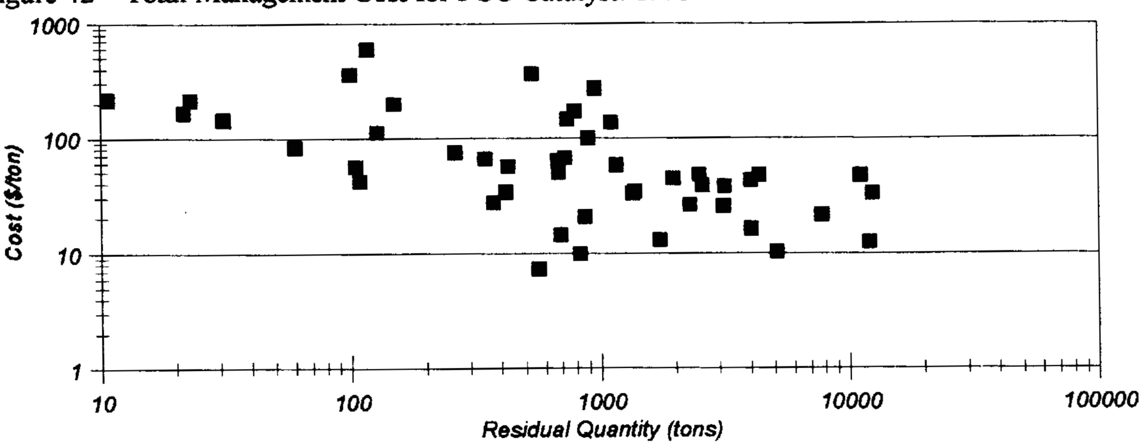


Figure 42—Total Management Cost for FCC Catalyst: 1995



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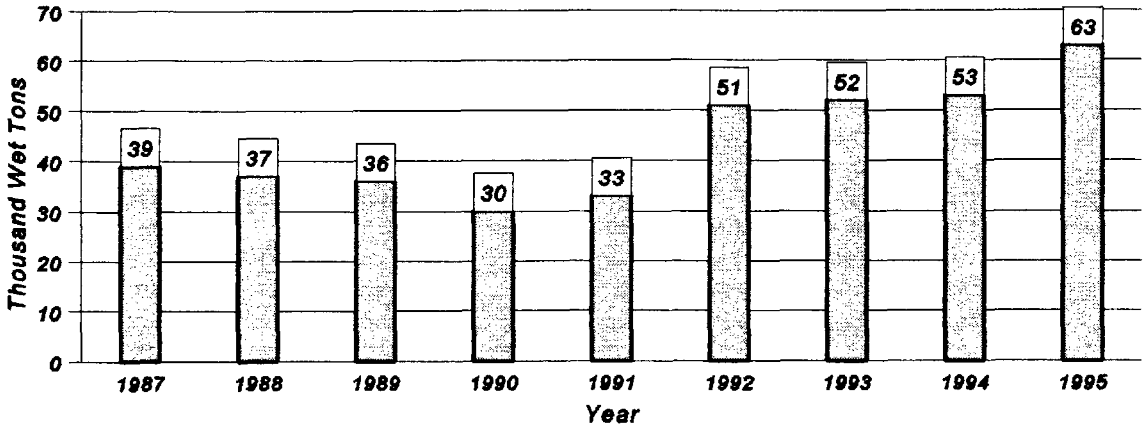
HYDRO. CATALYST[6]

The U.S. petroleum refining industry managed an estimated 63 thousand wet tons of Hydro-processing Catalysts in 1995, which was an 18% increase from 1994. A summary of the quantity of Hydro. Catalyst managed per year is presented in Figure 43.

Figure 43—Nationwide Estimates of Hydro. Catalyst per Year: 1987-1995.



The portion of the Hydro. Catalyst stream that is managed by each management practice is shown in Figure 44 for 1994 and 1995. Recycling continues to be the most common practice.

Figure 44—Nationwide Estimates of Hydro. Catalyst by Management Practice: 1994-1995.

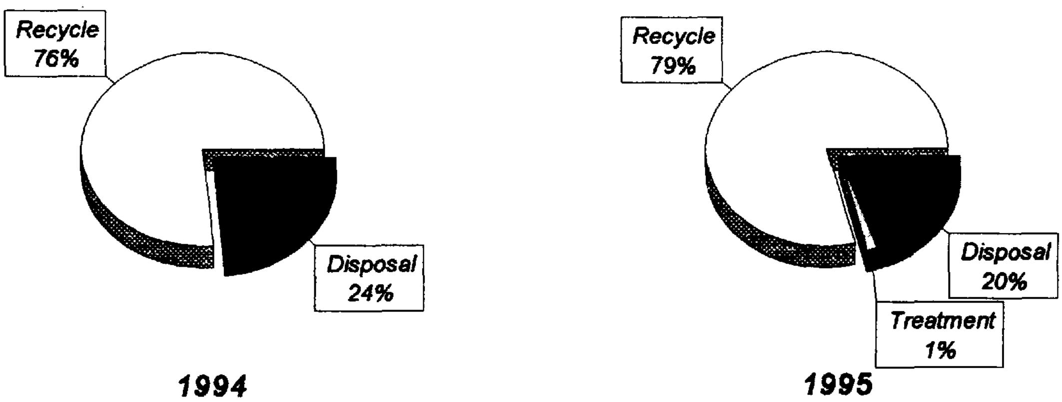


Figure 45 shows the Hydro. Catalyst distribution by management technique for 1994 and 1995. The dominant technique used to manage this stream is to recycle by *reclaiming* usable material from the spent catalysts.

[6]Recall that API uses labels such as Hydro. Catalyst in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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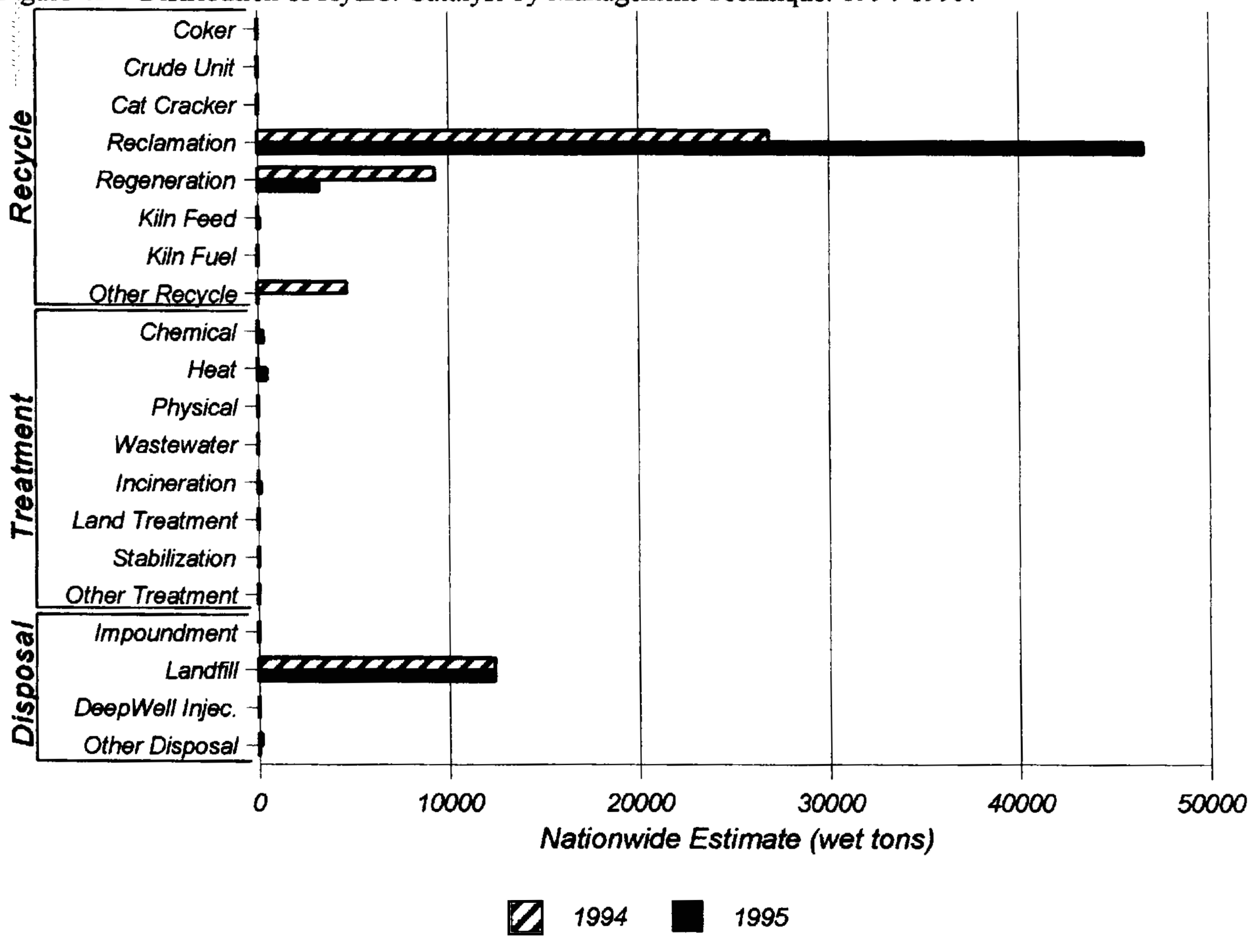
Figure 45—Distribution of Hydro. Catalyst by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: none.

Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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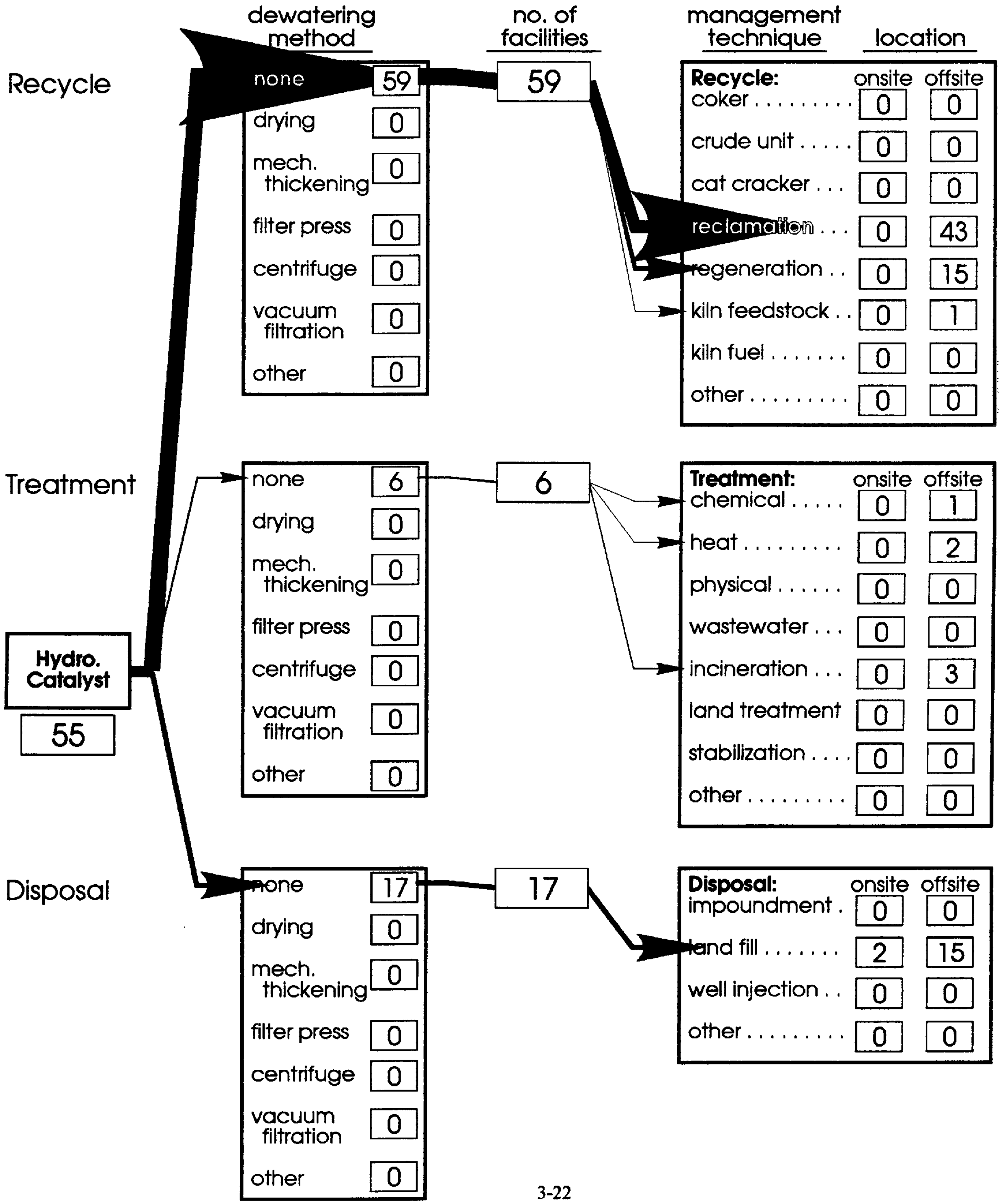
Figure 46 - Hydro. Catalyst Summary: 1995

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



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The following three graphs summarize the cost data reported for Hydro. Catalyst.

Figure 47—Onsite Management Cost for Hydro. Catalyst: 1995

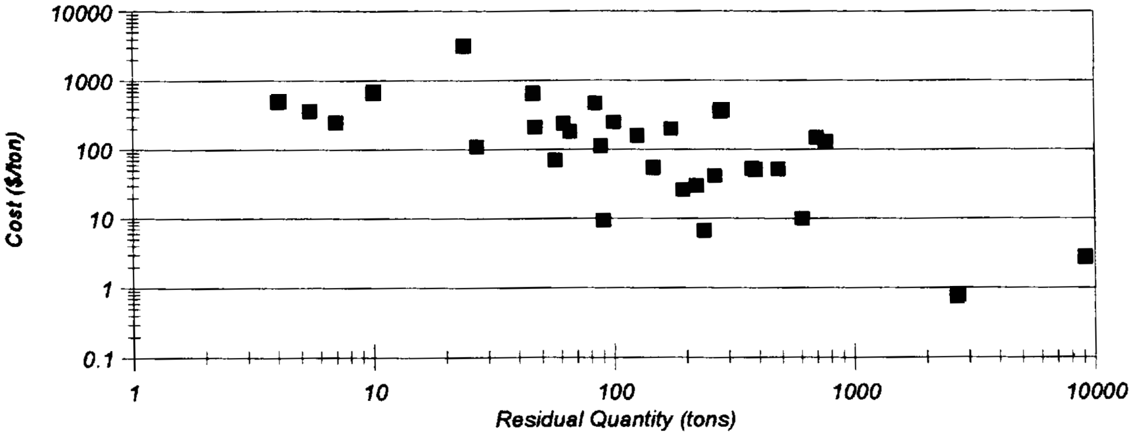


Figure 48—Offsite Management Cost for Hydro. Catalyst: 1995

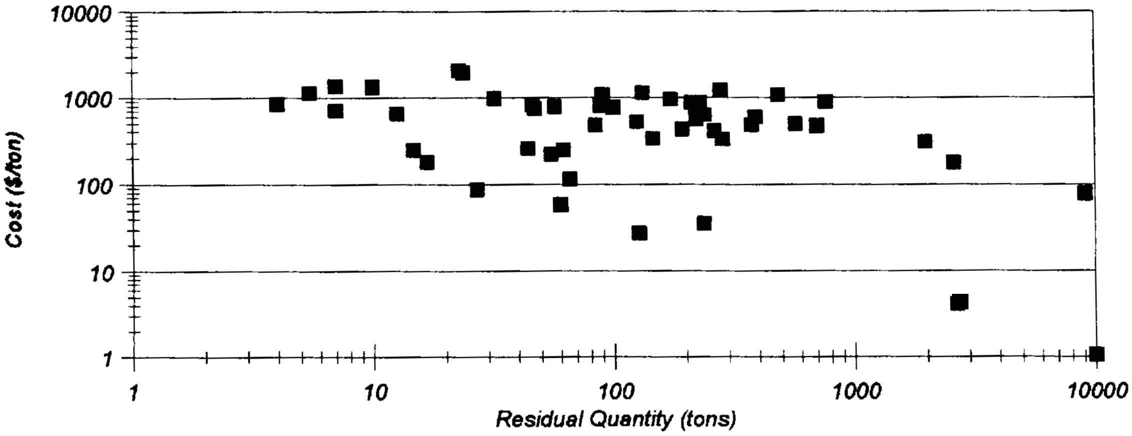
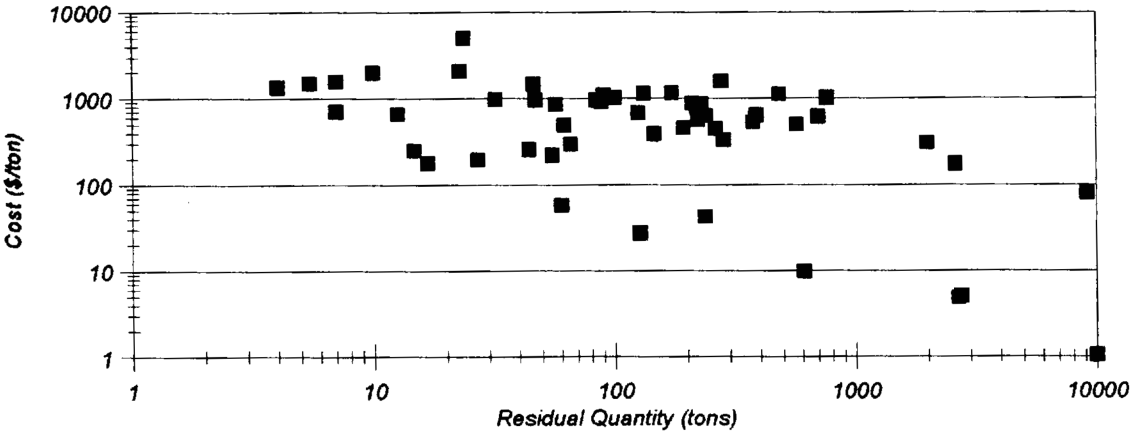


Figure 49—Total Management Cost for Hydro. Catalyst: 1995



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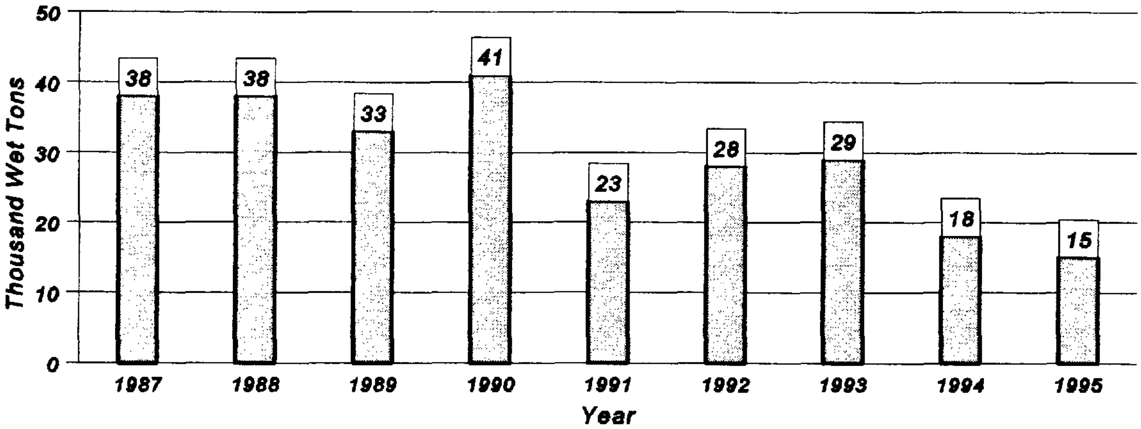
OTHER SPENT CATALYSTS[7]

The U.S. petroleum refining industry managed an estimated 15 thousand wet tons of Other Spent Catalysts in 1995, which was a 15% reduction from 1994. A summary of the quantity of Other Spent Catalysts managed per year is presented in Figure 50.

Figure 50—Nationwide Estimates of Other Spent Catalysts per Year: 1987-1995.



The portion of the Other Spent Catalysts stream that is managed by each management practice is shown in Figure 51 for 1994 and 1995. Disposal continues to be the most common practice.

Figure 51—Nationwide Estimates of Other Spent Catalysts by Management Practice: 1994-1995.

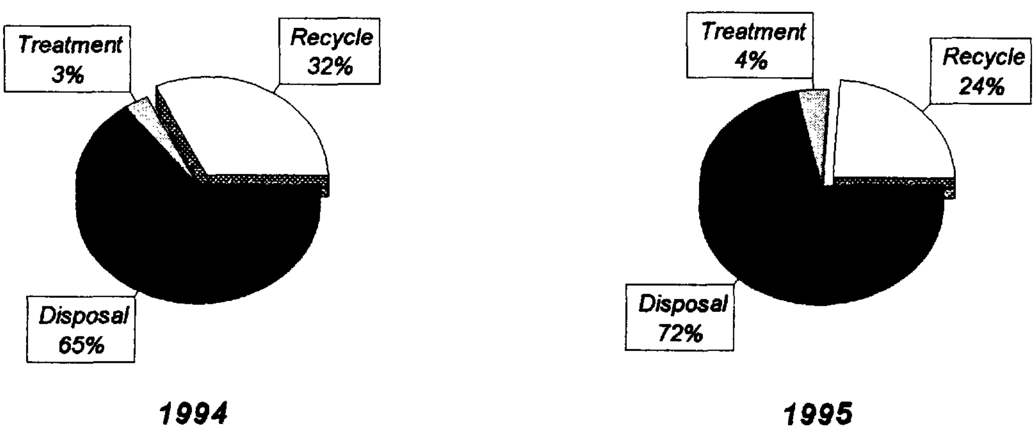


Figure 52 shows the Other Spent Catalysts distribution by management technique for 1994 and 1995. The dominant technique used to manage this stream is to dispose of the material in a *landfill*.

[7]Recall that this report uses labels such as Other Spent Catalysts in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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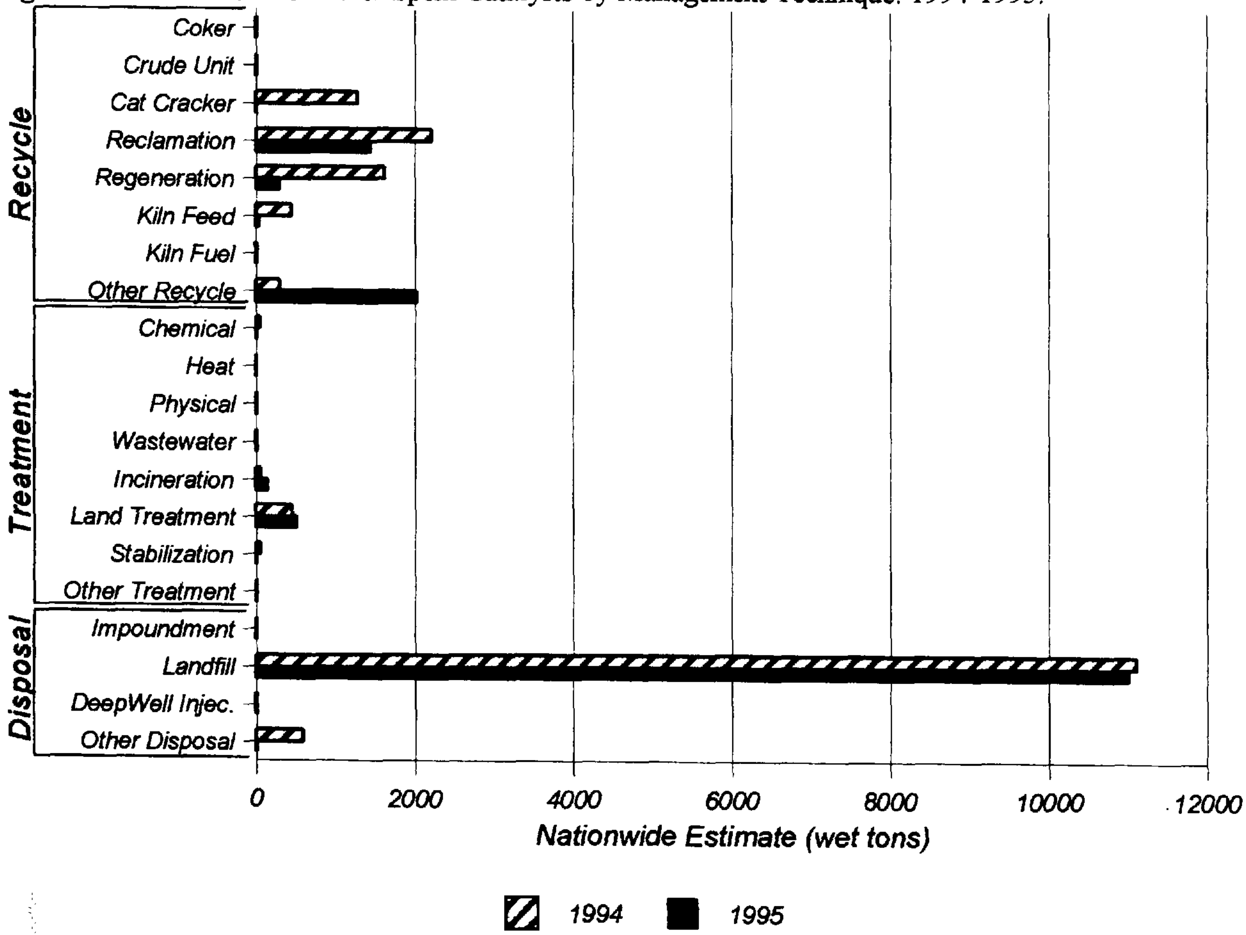
Figure 52—Distribution of Other Spent Catalysts by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: one facility listed reuse as feed for a fertilizer facility, and another indicated that spent catalysts are sold as a product to the aluminum industry.

Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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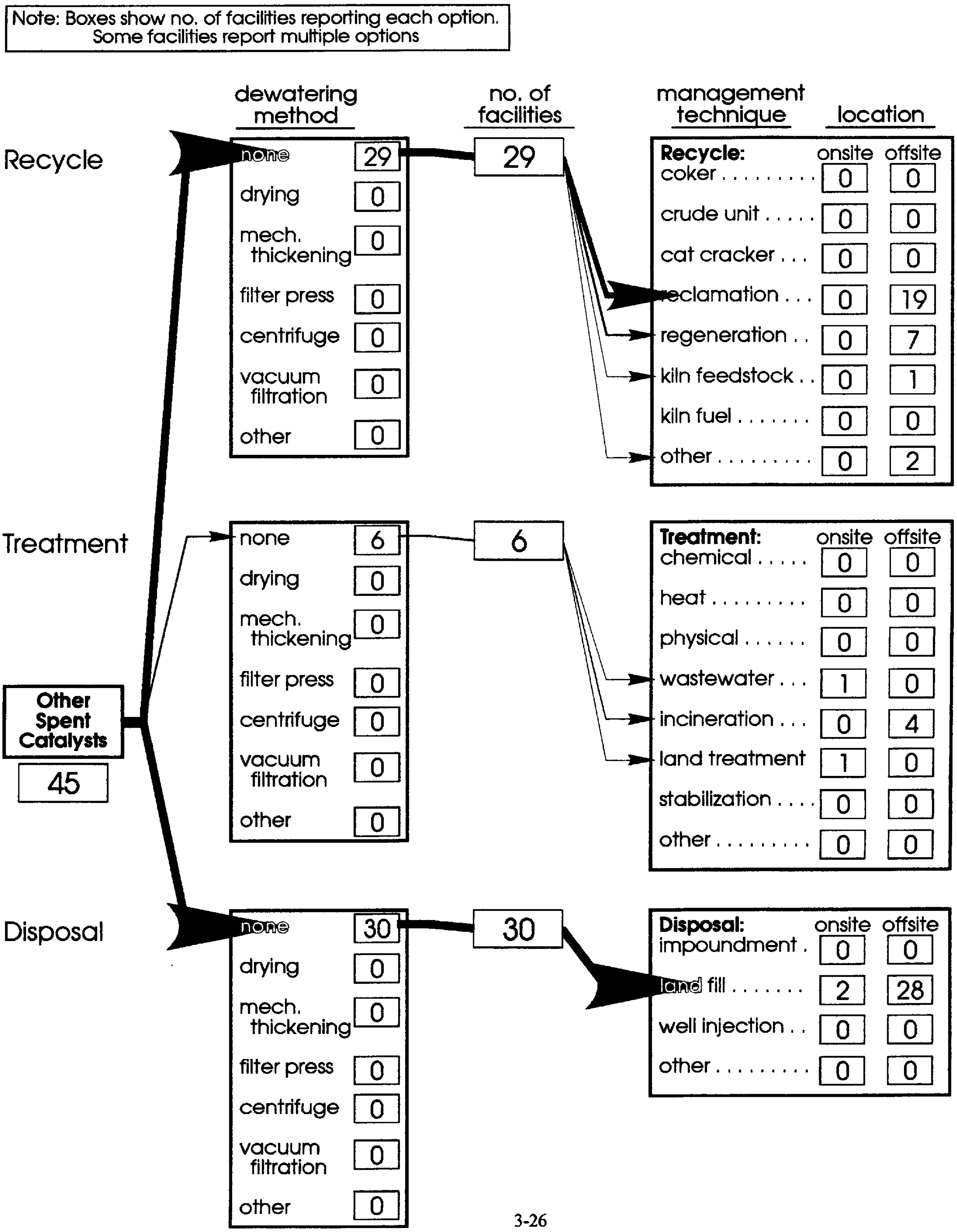
Figure 53 - Other Spent Catalysts Summary: 1995



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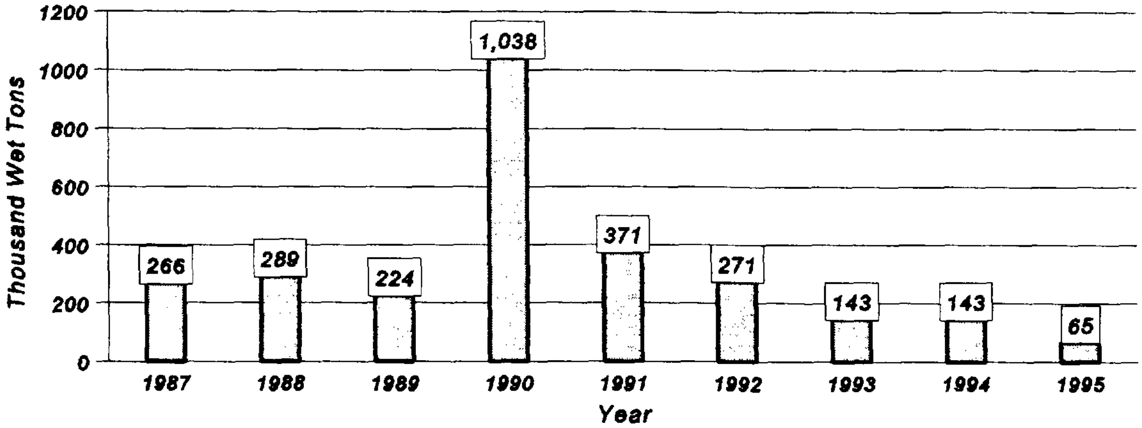
POND SEDIMENTS[8]

The U.S. petroleum refining industry managed an estimated 65 thousand wet tons of Pond Sediments in 1995, which was a 54% reduction from 1994. A summary of the quantity of Pond Sediments managed per year is presented in Figure 54. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

Figure 54—Nationwide Estimates of Pond Sediments per Year: 1987-1995.



The portion of the Pond Sediments stream that is managed by each management practice is shown in Figure 55 for 1994 and 1995. Recognizing only the actual residual stream, and not recovered oil or water, disposal continues to be the most common practice.

Figure 55—Nationwide Estimates of Pond Sediments by Management Practice: 1994-1995.

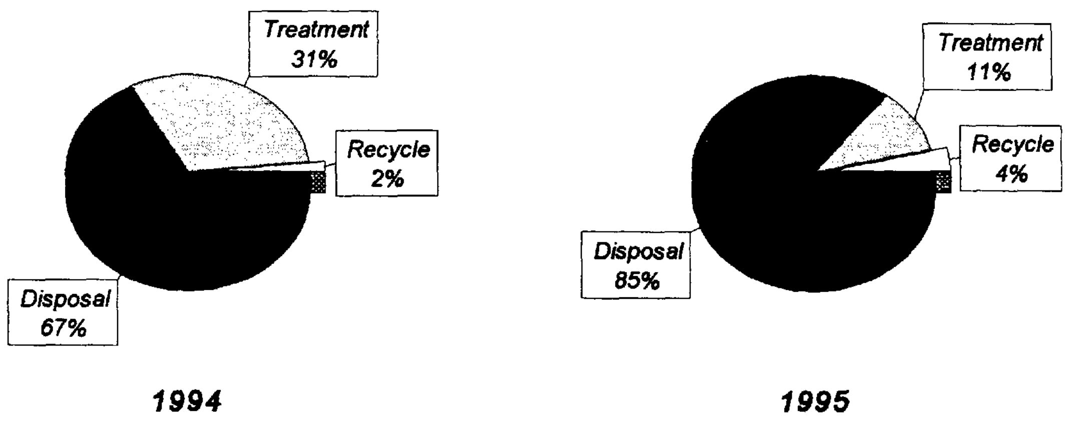


Figure 56 shows the Pond Sediments distribution by management technique for 1994 and 1995. The dominant technique used to manage this stream is to dispose of the material in a *landfill*.

[8]Recall that this report uses labels such as Pond Sediments in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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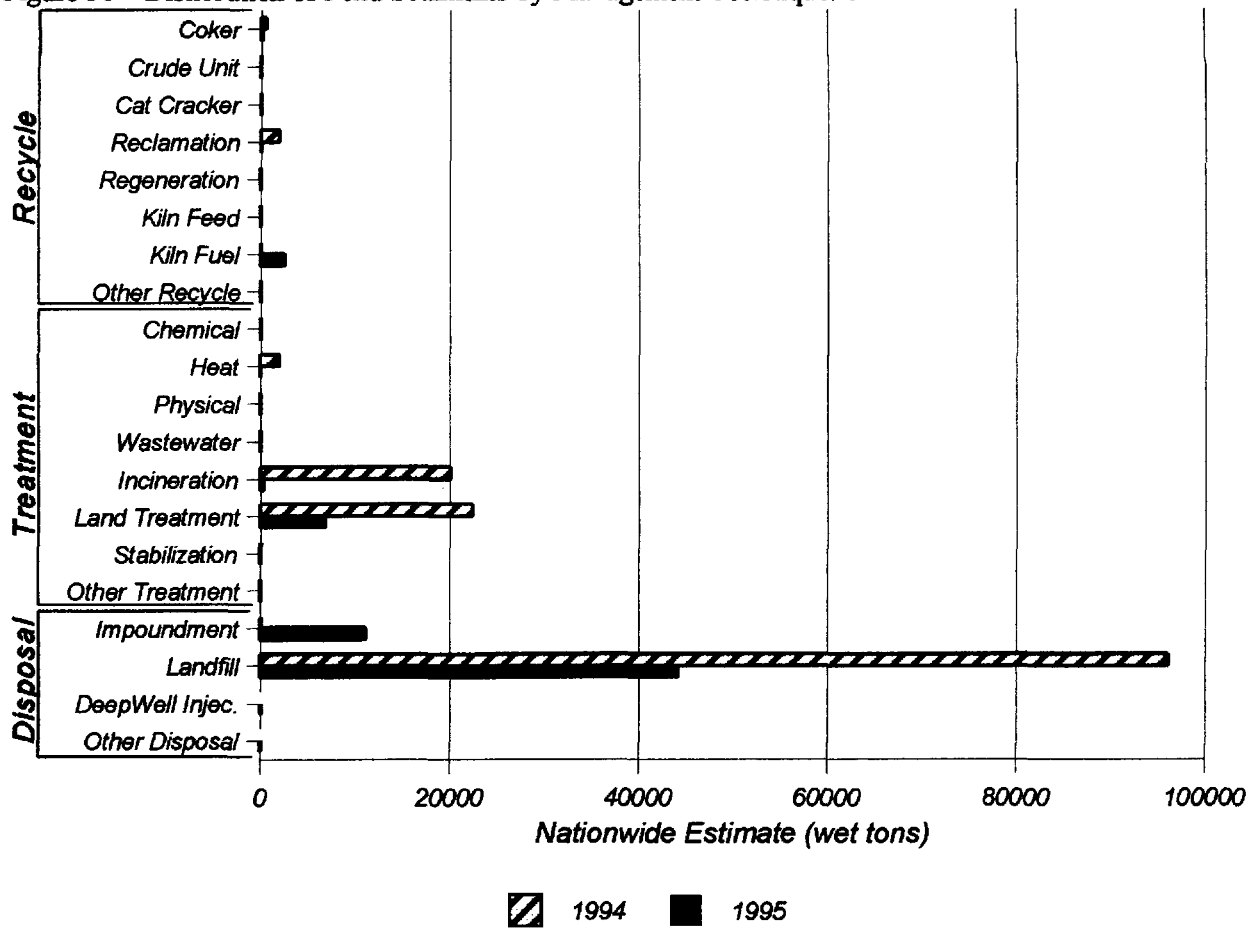
Figure 56—Distribution of Pond Sediments by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: none.

Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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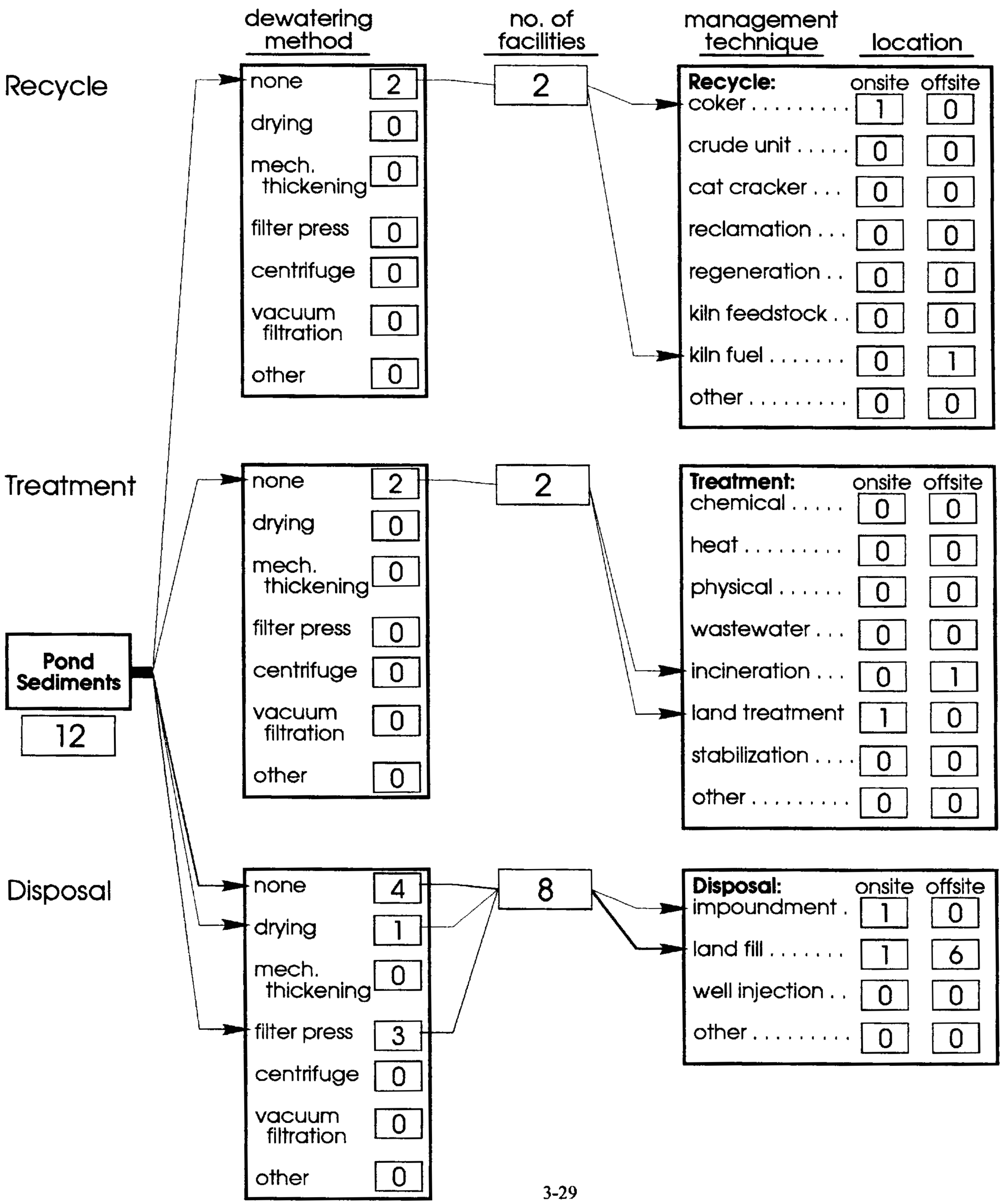
Figure 57 - Pond Sediments Summary: 1995

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



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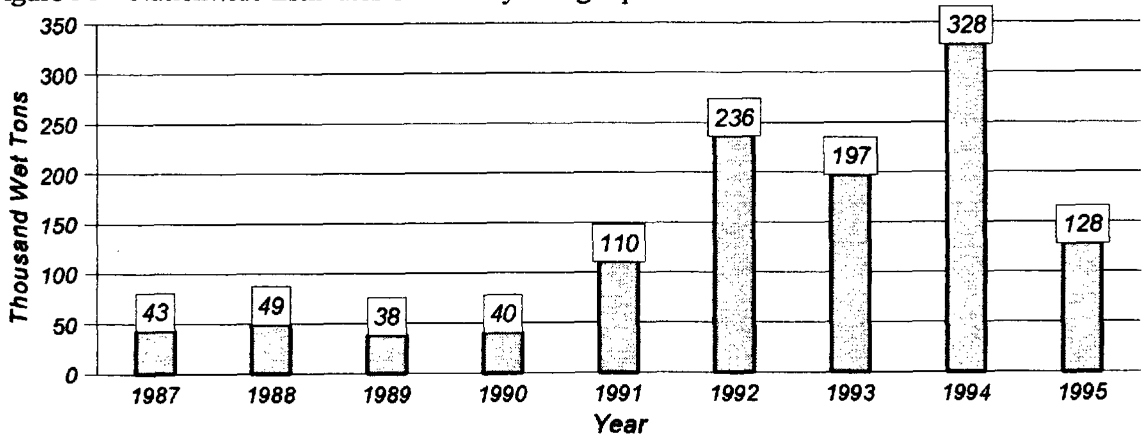
PRIMARY SLUDGES[9]

The U.S. petroleum refining industry managed an estimated 128 thousand wet tons of Primary Sludges in 1995, which was a 61% reduction from 1994. A summary of the quantity of Primary Sludges managed per year is presented in Figure 58. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

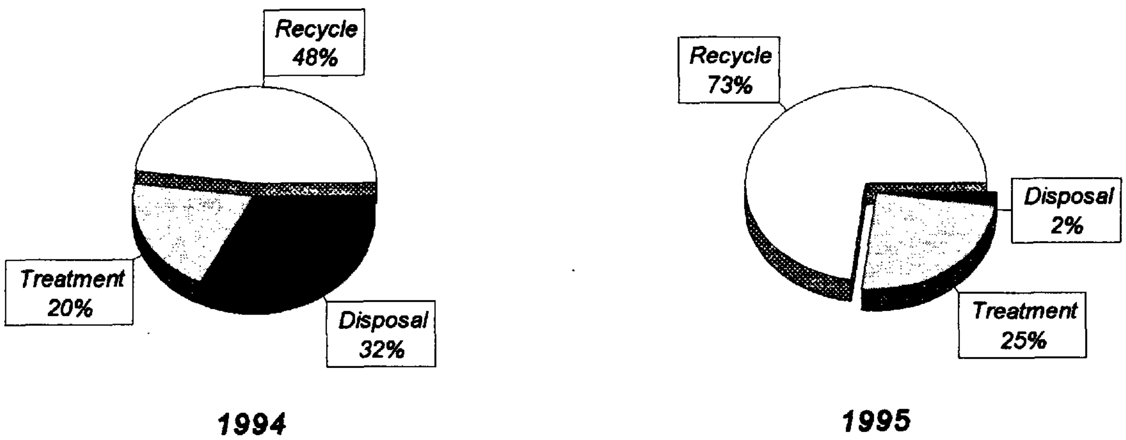
Figure 58—Nationwide Estimates of Primary Sludges per Year: 1987-1995.



Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantities of these oily wastewater streams are summarized in Figure 85.

The portion of the Primary Sludges stream that is managed by each management practice is shown in Figure 59 for 1994 and 1995. Recognizing only the actual residual stream, and not recovered oil or water, has shown recycling to be the most common practice.

Figure 59—Nationwide Estimates of Primary Sludges by Management Practice: 1994-1995.



[9]Recall that this report uses labels such as Primary Sludges in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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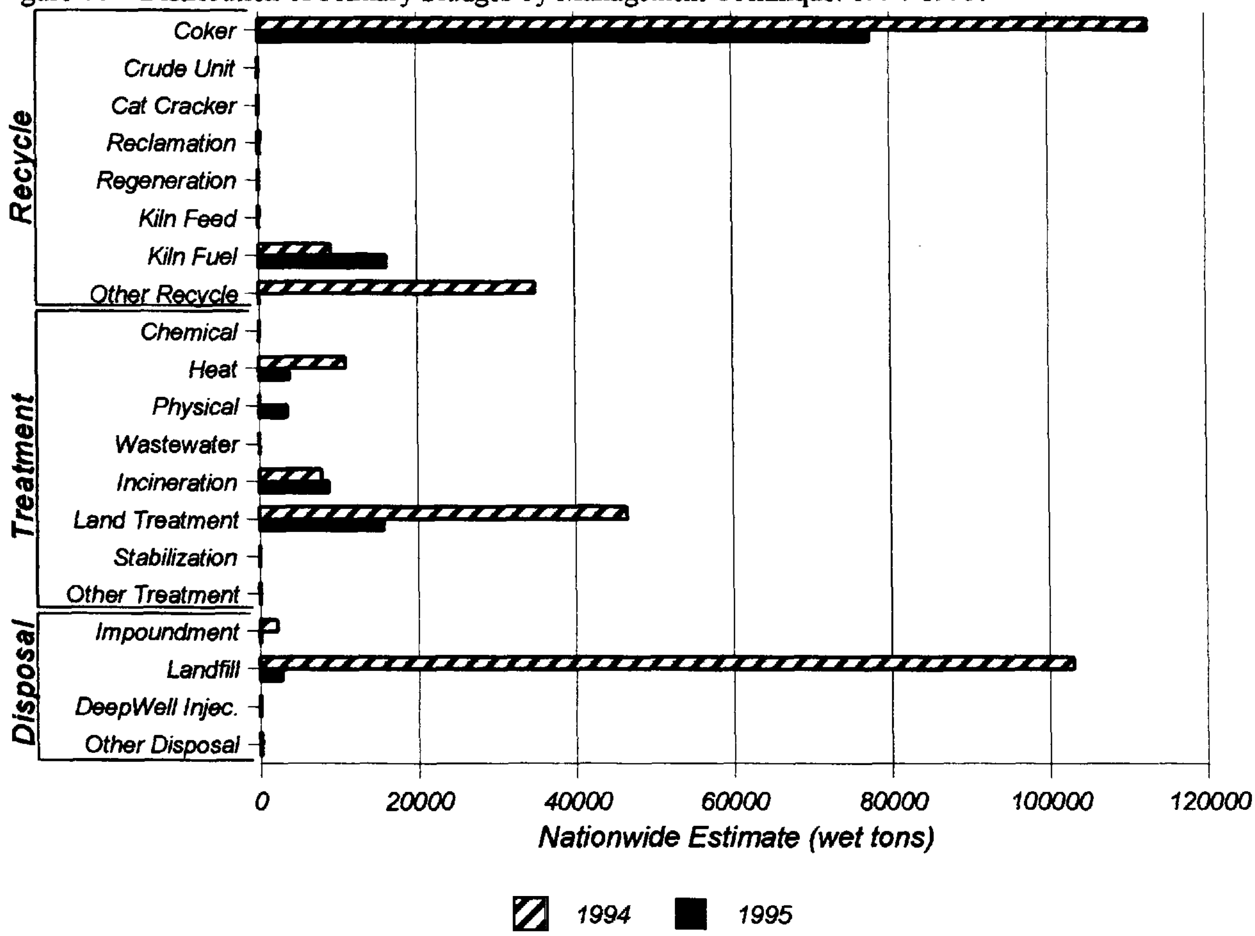
Figure 60 shows the Primary Sludges distribution by management technique for 1994 and 1995. The quantities shown for recycling to the *crude unit* and for *wastewater* treatment have gone to zero, in that recovered oil and water from dewatering operations are not truly residuals and are no longer included.

Figure 60—Distribution of Primary Sludges by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: none.

Other Treatment: none.

Other Disposal: one facility sends oily sludges to a T.S.D.F. facility for disposal.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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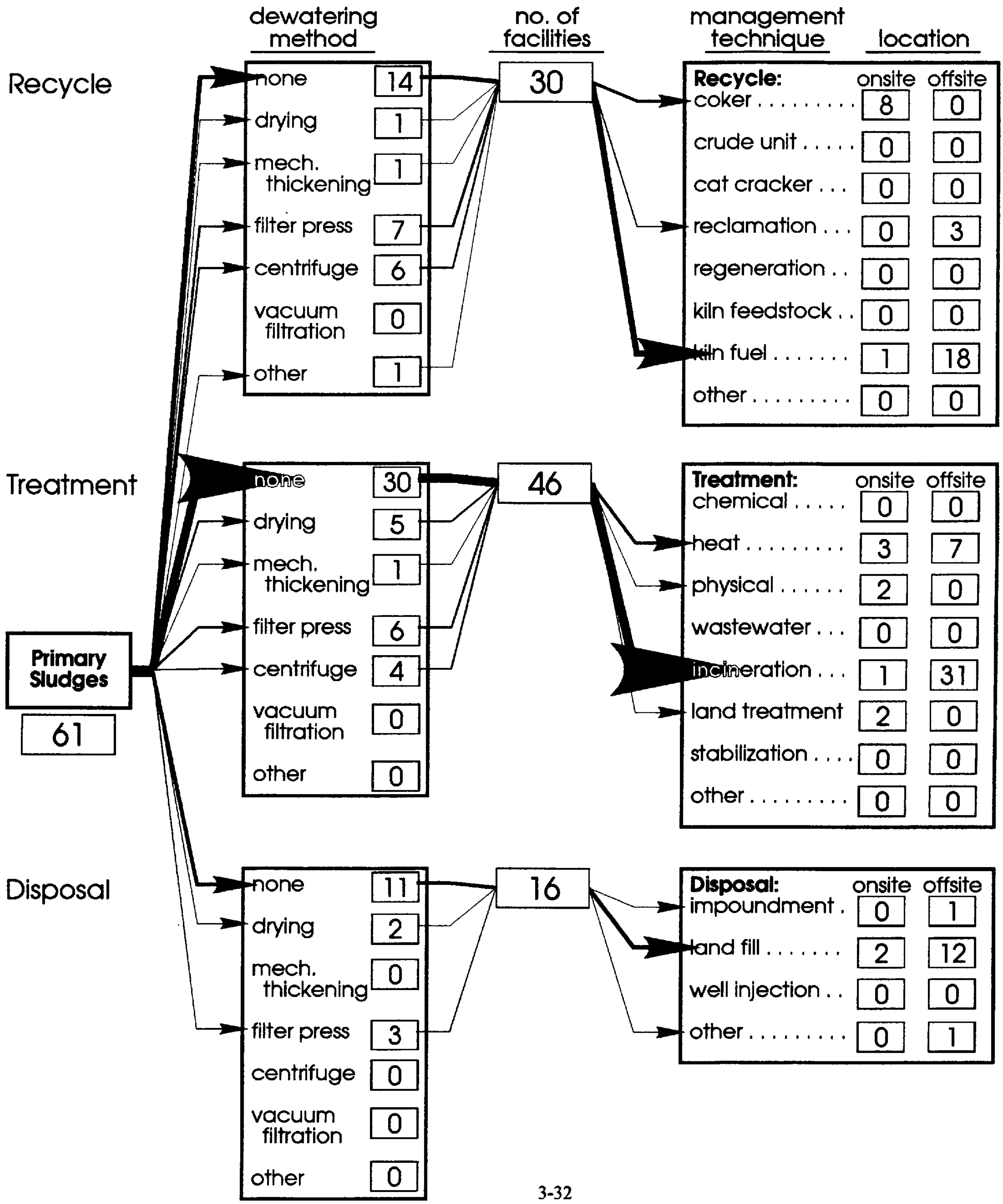
Figure 61 - Primary Sludges Summary: 1995

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



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The following three graphs summarize the cost data reported for Primary Sludges.

Figure 62—Onsite Management Cost for Primary Sludges: 1995

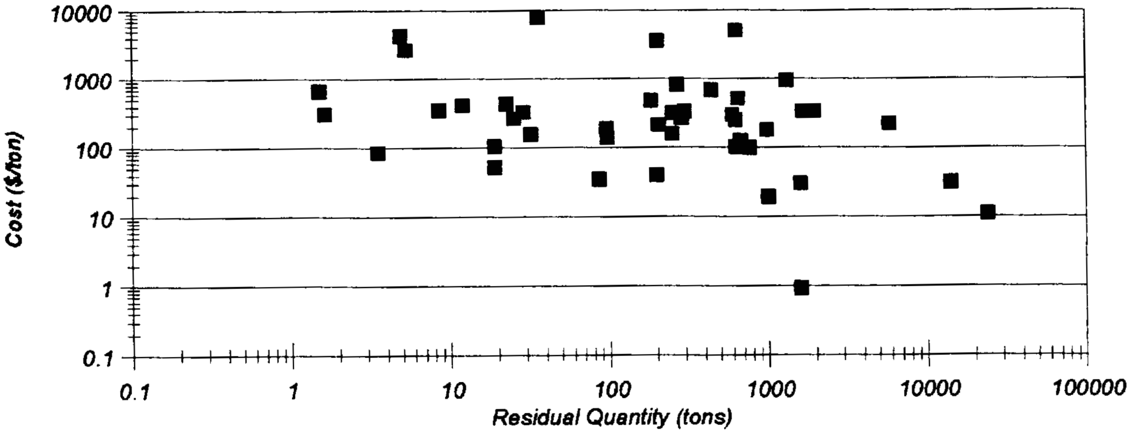


Figure 63—Offsite Management Cost for Primary Sludges: 1995

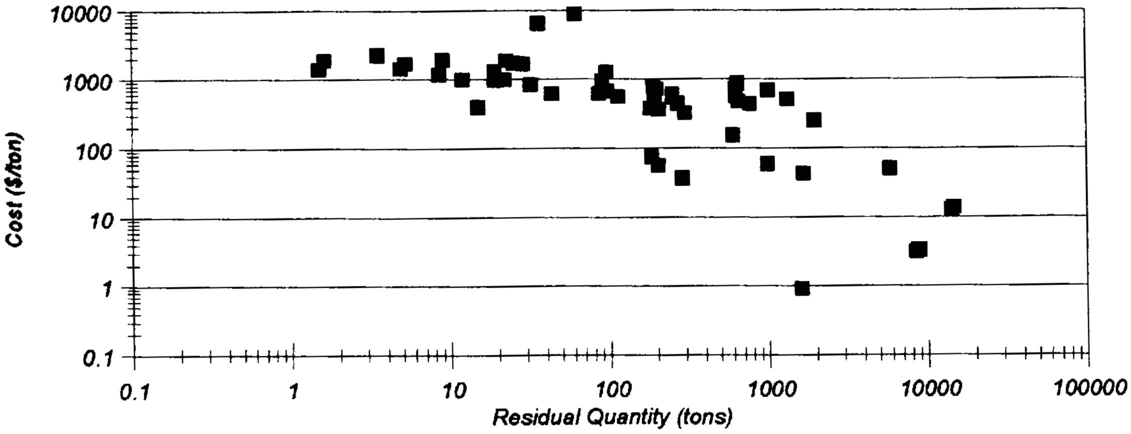
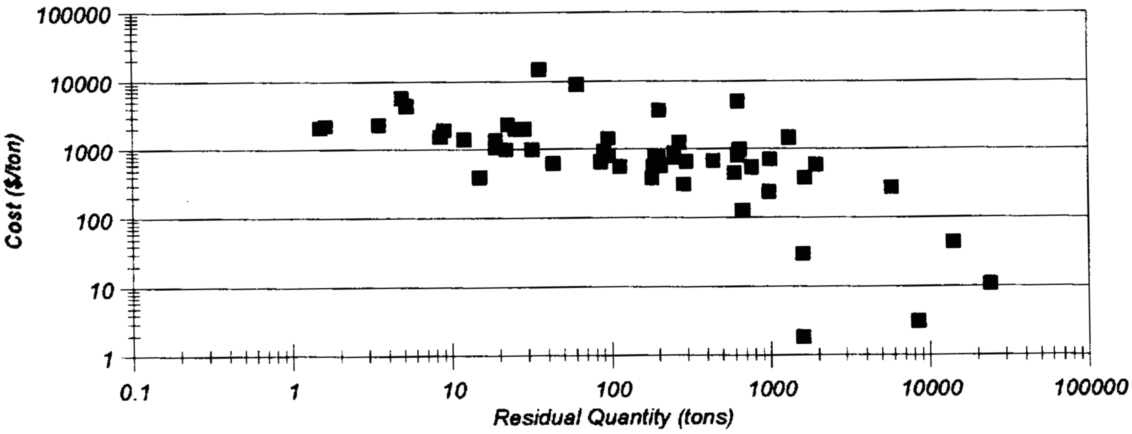


Figure 64—Total Management Cost for Primary Sludges: 1995



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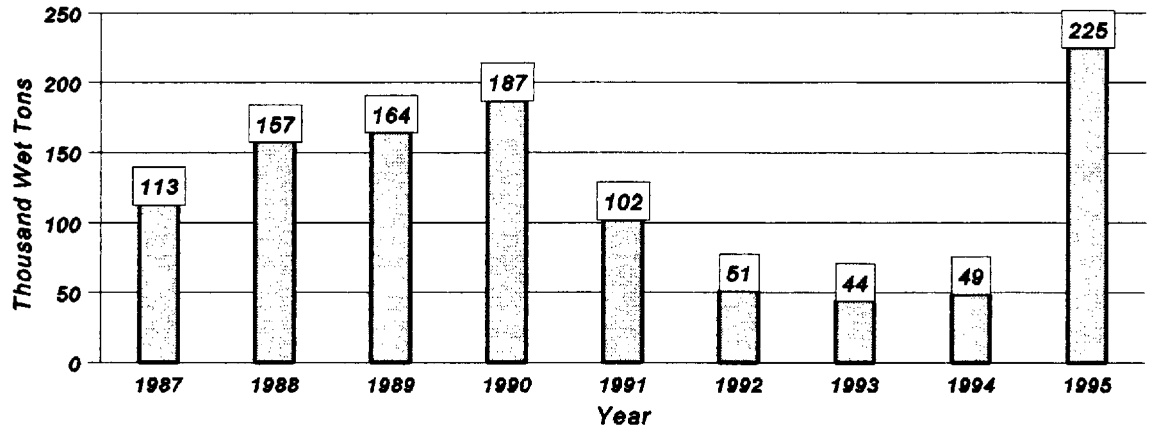
SLOP OIL EMULSION SOLIDS[10]

The U.S. petroleum refining industry managed an estimated 225 thousand wet tons of Slop Oil Emulsion Solids in 1995, which was a 362% increase from 1994. A summary of the quantity of Slop Oil Emulsion Solids managed per year is presented in Figure 65. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered water rather than true residuals.

Figure 65—Nationwide Estimates of Slop Oil Emulsion Solids per Year: 1987-1995.



Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantities of these oily wastewater streams are summarized in Figure 85, which shows a decrease from 833 thousand wet tons in 1994 to 554 thousand wet tons in 1995, a reduction of 33%.

The portion of the Slop Oil Emulsion Solids stream that is managed by each management practice is shown in Figure 66 for 1994 and 1995. Recycling continues to be the most common practice.

Figure 66—Nationwide Estimates of Slop Oil Emulsion Solids by Management Practice: 1994-1995.

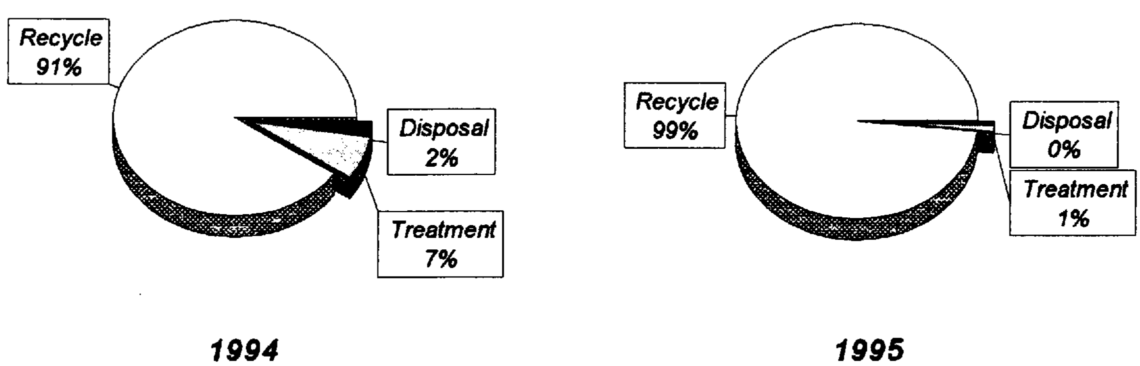


Figure 67 shows the Slop Oil Emulsion Solids distribution by management technique for 1994 and 1995.

[10]Recall that this report uses labels such as Slop Oil Emulsion Solids in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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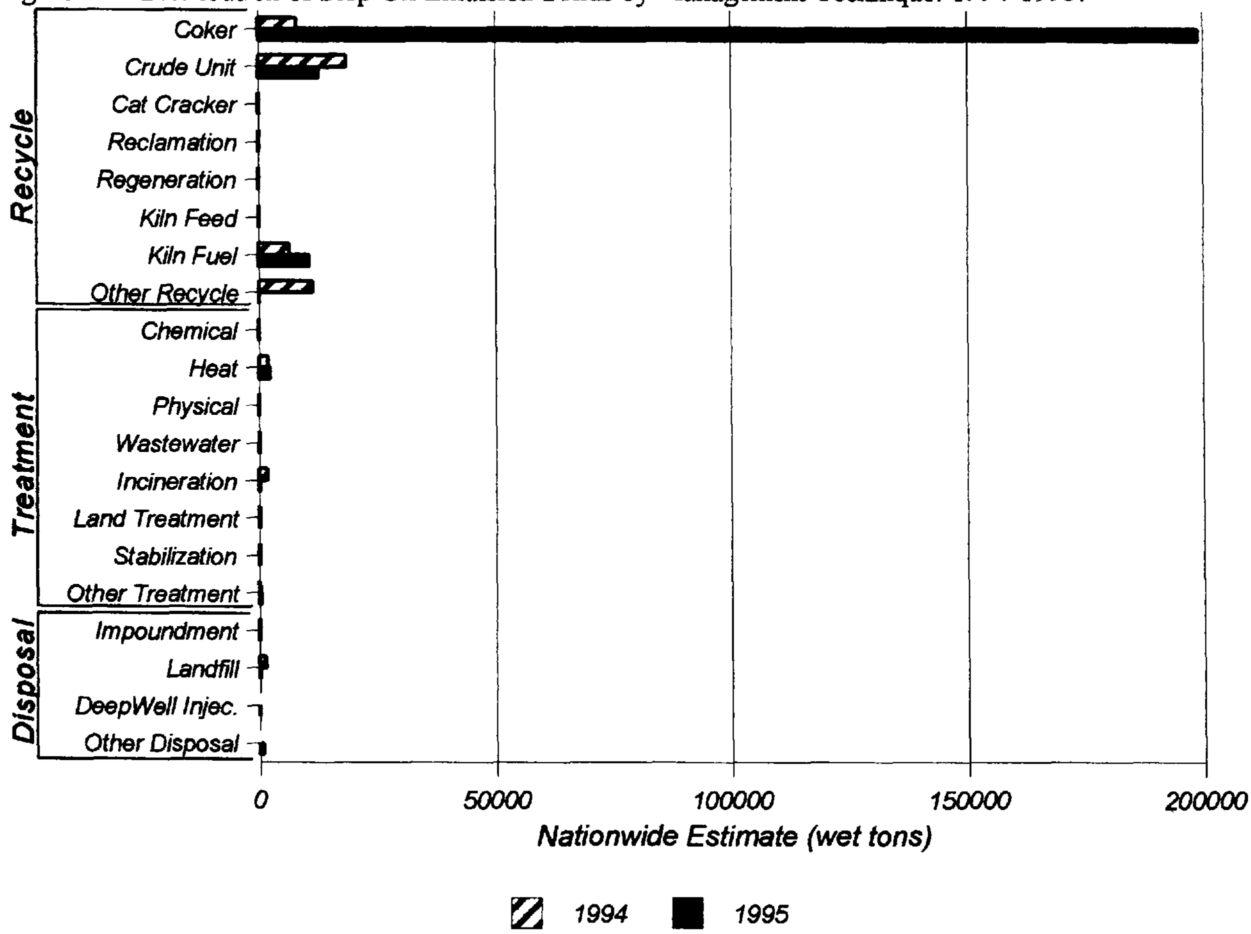
The quantity shown for *wastewater* treatment has gone to zero, in that recovered water from dewatering operations is not truly a residual and is no longer included. The dominant technique is to recycle the material by routing it to the *coker*.

Figure 67—Distribution of Slop Oil Emulsion Solids by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: none.

Other Treatment: one facility uses a proprietary biological process to treat oily sludges.

Other Disposal: one facility sends oily sludges to a T.S.D.F. facility for disposal.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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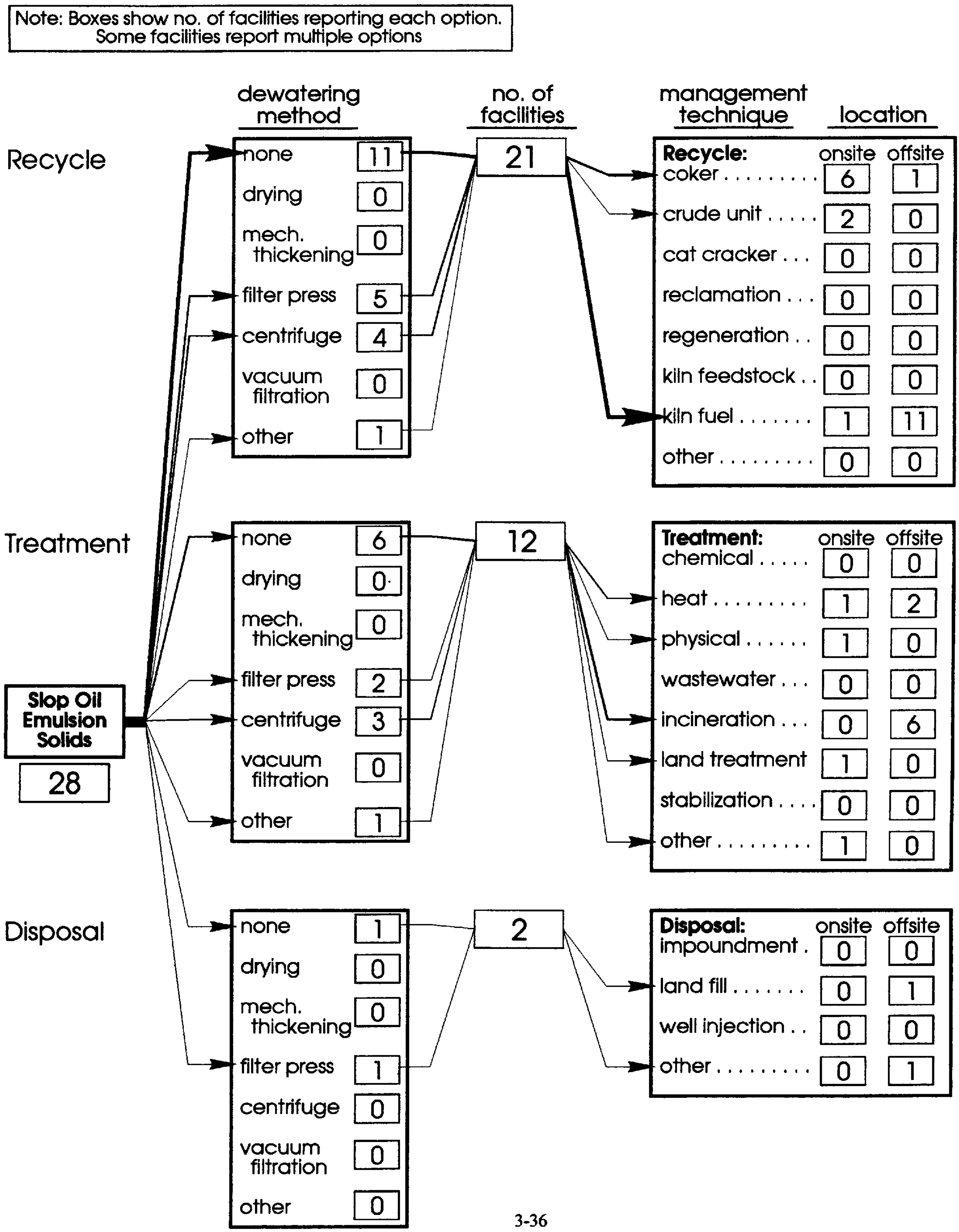
Figure 68 - Slop Oil Emulsion Solids Summary: 1995



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SPENT CRESYLIC CAUSTIC[11]

The U.S. petroleum refining industry managed an estimated 153 thousand wet tons of Spent Cresylic Caustic in 1995, which was a 2% reduction from 1994. This caustic was not identified as a separate residual stream prior to 1994, so a summary of the quantity of this stream managed by year is not available. Figure 88, however, presents a summary of the quantity of Total Spent Caustics managed per year since 1987.

The portion of the Spent Cresylic Caustic stream that is managed by each management practice is shown in Figure 69 for 1994 and 1995. Recycling continues to be the most common practice.

Figure 69—Nationwide Estimates of Spent Cresylic Caustic by Management Practice: 1994-1995.

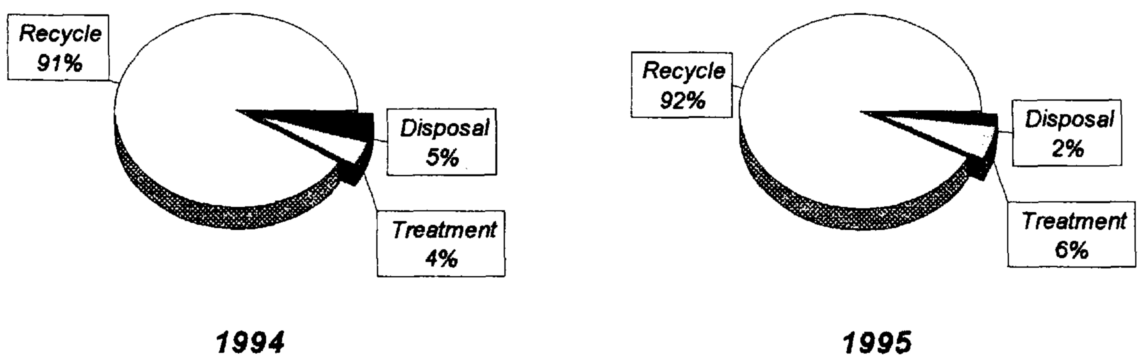

Figure 70 shows the Spent Cresylic Caustic distribution by management technique for 1994 and 1995. Numerous respondents listed quantities under *other recycle* that had actually been recycled by *reclaiming* usable material from the spent catalysts. Moving these entries to their appropriate category resulted in *reclamation* being the dominant technique used to manage this stream.

[11]Recall that this report uses labels such as Spent Cresylic Caustic in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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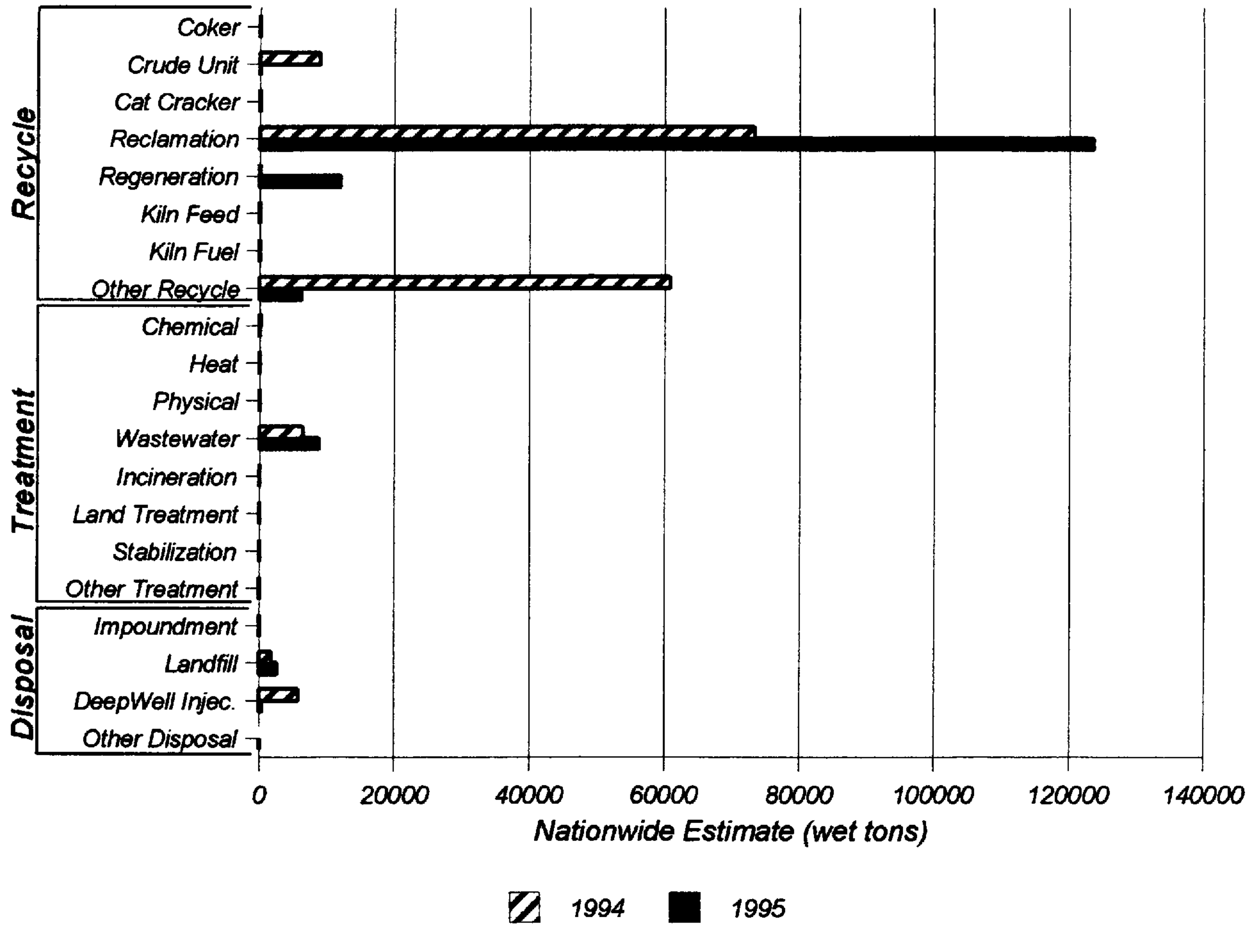
Figure 70—Nationwide Estimates of Distribution of Spent Cresylic Caustic by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: two facilities indicate that spent cresylic caustic is combined with spent sulfidic caustic and sold as an unspecified product, another indicates selling spent cresylic caustic to a chemical company, and two others list reusing it for corrosion control (pH balance).

Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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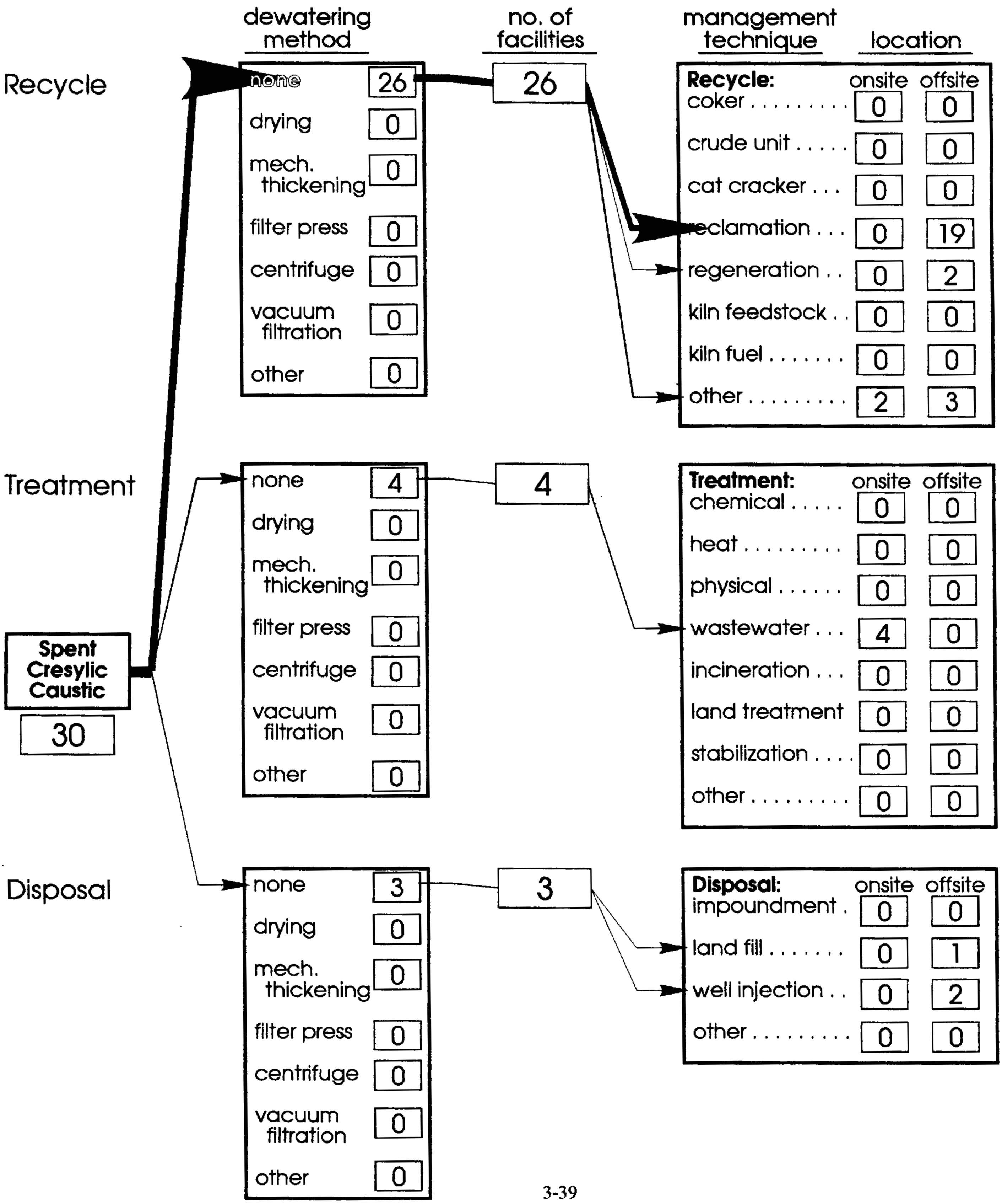
Figure 71 - Spent Cresylic Caustic Summary: 1995

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



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SPENT NAPHTHENIC CAUSTIC[12]

The U.S. petroleum refining industry managed an estimated 145 thousand wet tons of Spent Naphthenic Caustic in 1995, which was a 34% reduction from 1994. This caustic was not identified as a separate residual stream prior to 1994, so a summary of the quantity of this stream managed by year is not available. Figure 88, however, presents a summary of the quantity of Total Spent Caustics managed per year since 1987.

The portion of the Spent Naphthenic Caustic stream that is managed by each management practice is shown in Figure 72 for 1994 and 1995. Recycling continues to be the most common practice.

Figure 72—Nationwide Estimates of Spent Naphthenic Caustic by Management Practice: 1994-1995.

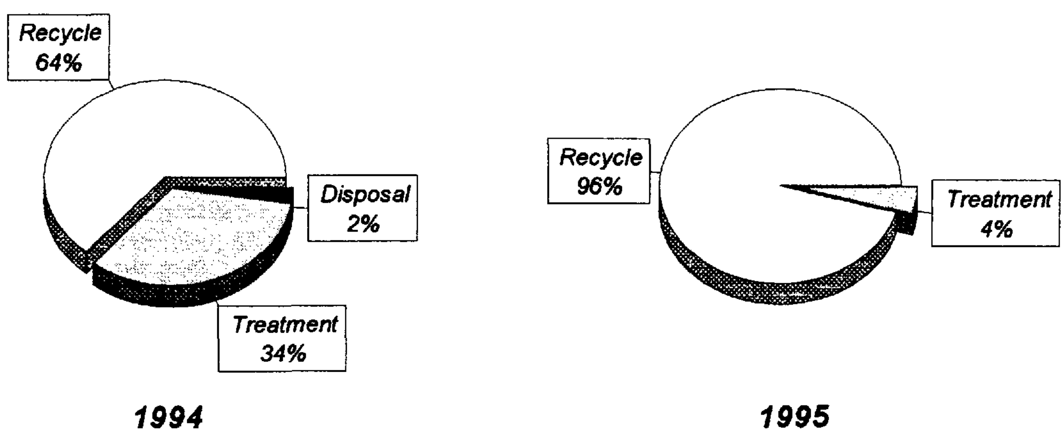

Figure 73 shows the Spent Naphthenic Caustic distribution by management technique for 1994 and 1995. Numerous respondents listed quantities under *other recycle* that had actually been recycled by *reclaiming* usable material from the spent catalysts. Moving these entries to their appropriate category resulted in *reclamation* being the dominant technique used to manage this stream.

[12]Recall that this report uses labels such as Spent Naphthenic Caustic in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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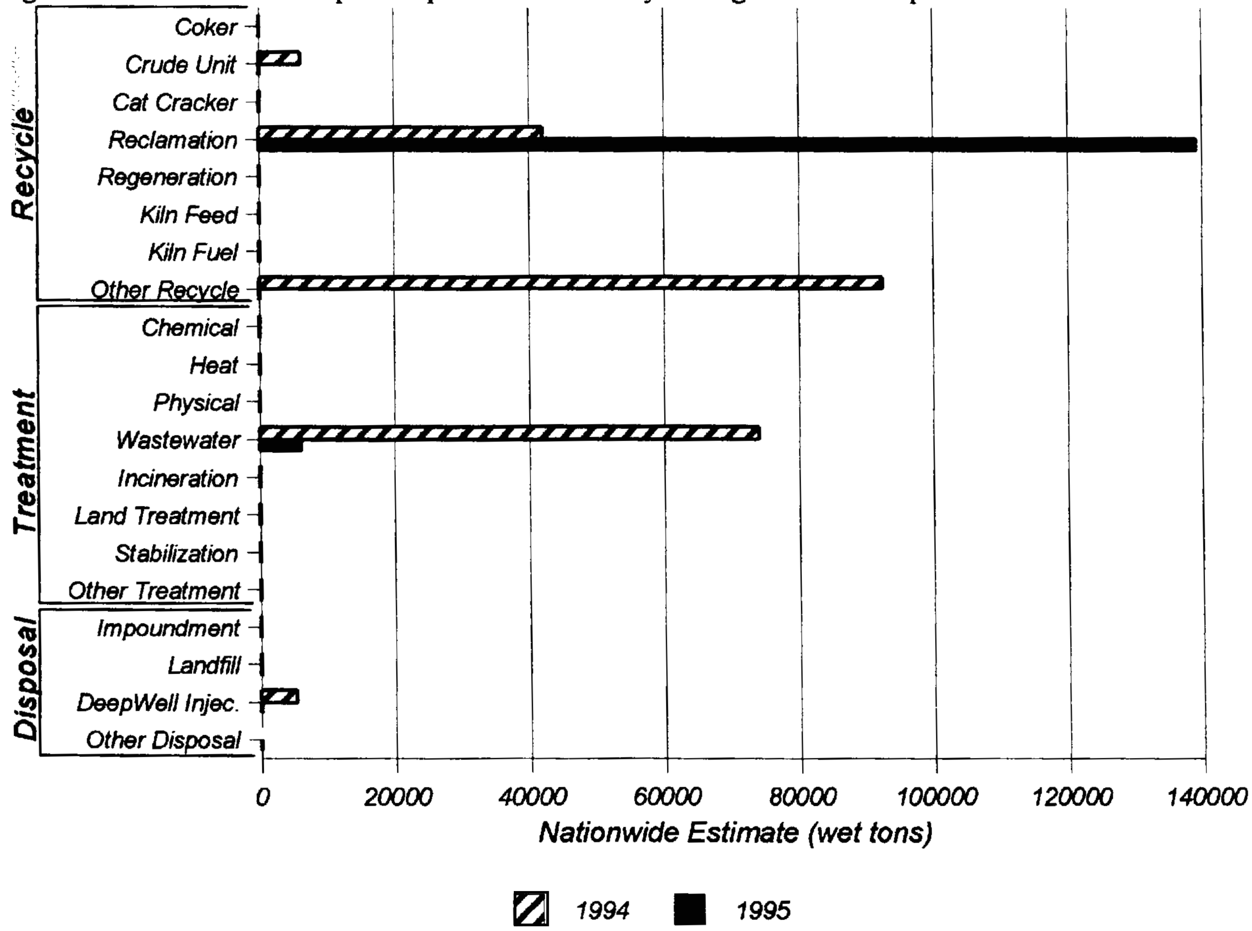
Figure 73—Distribution of Spent Naphthenic Caustic by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: none.

Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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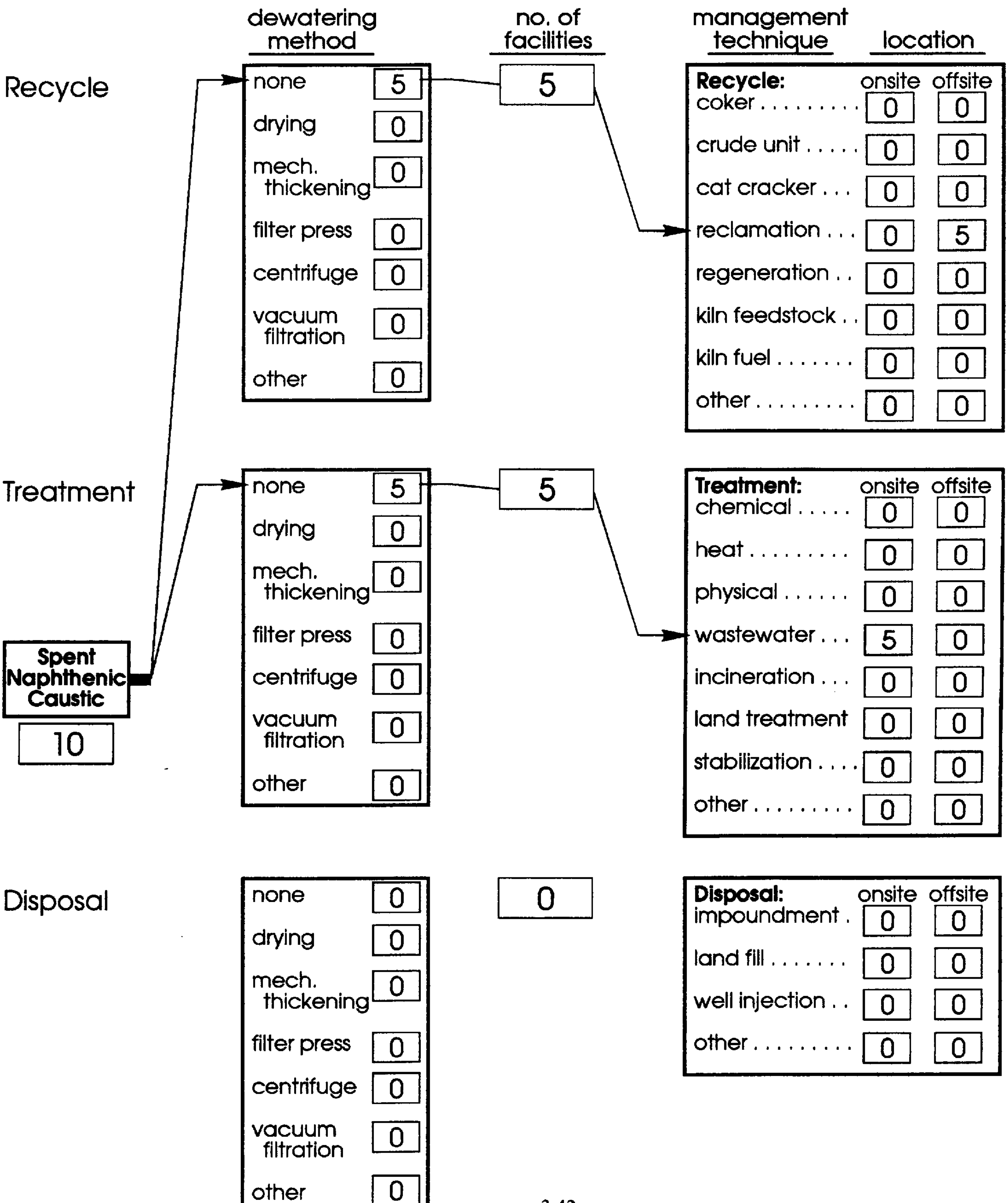
Figure 74 - Spent Naphthenic Caustic Summary: 1995

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



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SPENT SULFIDIC CAUSTIC[13]

The U.S. petroleum refining industry managed an estimated 690 thousand wet tons of Spent Sulfidic Caustic in 1995, which was a 31% reduction from 1994. This caustic was not identified as a separate residual stream prior to 1994, so a summary of the quantity of this stream managed by year is not available. Figure 88, however, presents a summary of the quantity of Total Spent Caustics managed per year since 1987.

The portion of the Spent Sulfidic Caustic stream that is managed by each management practice is shown in Figure 75 for 1994 and 1995. Recycling has become the most common practice.

Figure 75—Nationwide Estimates of Spent Sulfidic Caustic by Management Practice: 1994-1995.

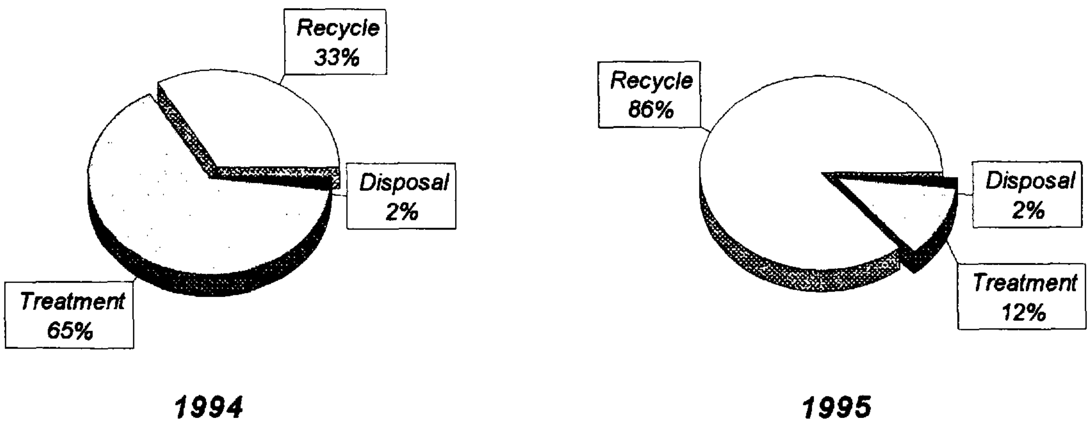

Figure 76 shows the Spent Sulfidic Caustic distribution by management technique for 1994 and 1995. The dominant technique had been to manage this stream in the *wastewater* treatment facility, but the 1995 survey has shown a shift toward *regeneration*. The significant quantity estimated for *regeneration* is due primarily to the survey responses of one company with multiple facilities.

[13]Recall that this report uses labels such as Spent Sulfidic Caustic in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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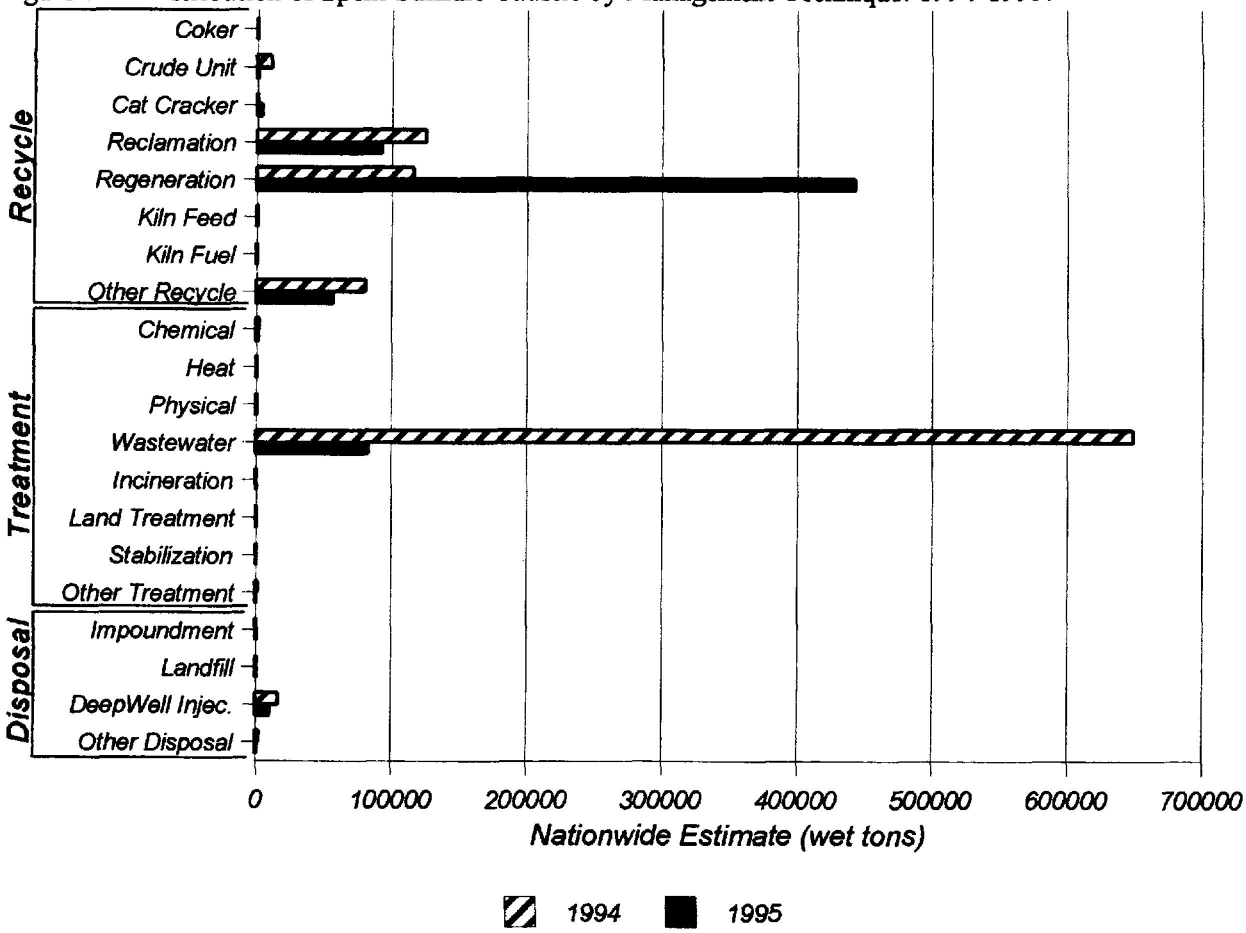
Figure 76—Distribution of Spent Sulfidic Caustic by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: five facilities reuse spent sulfidic caustic onsite for pH control.

Fifteen facilities indicated that they sell this material offsite as a product other than the standard categories. Of these, five facilities did not list the end use, two indicated reuse in the chemical industry, seven listed the paper industry as the end user, and one facility responded that they installed a reactor to produce saleable Sodium Hydrosulfide.

Other Treatment: none.

Other Disposal: one facility sends spent sulfidic caustic offsite for neutralization and disposal.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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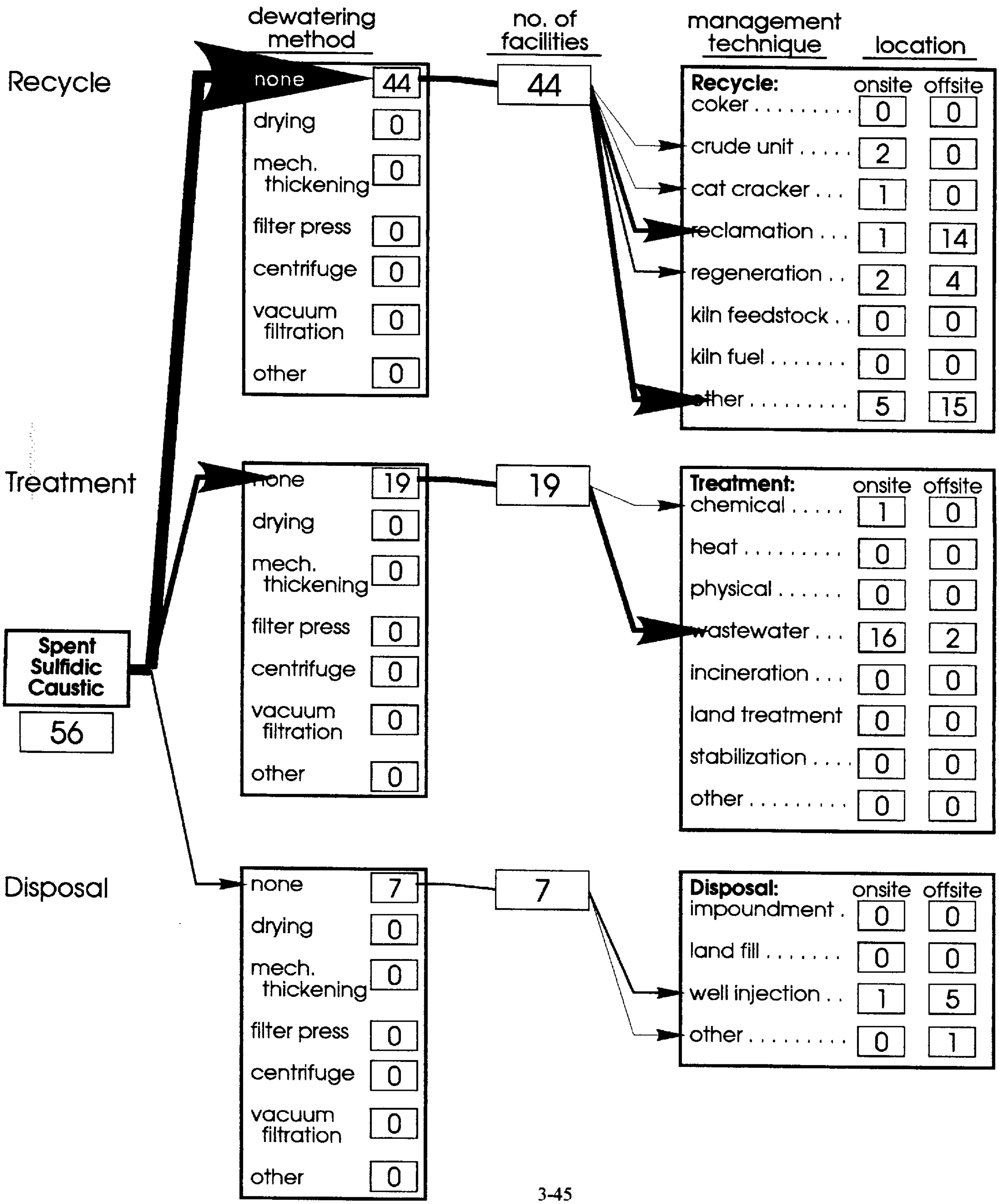
Figure 77 - Spent Sulfidic Caustic Summary: 1995

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



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The following three graphs summarize the cost data reported for Spent Sulfidic Caustic.

Figure 78—Onsite Management Cost for Spent Sulfidic Caustic: 1995

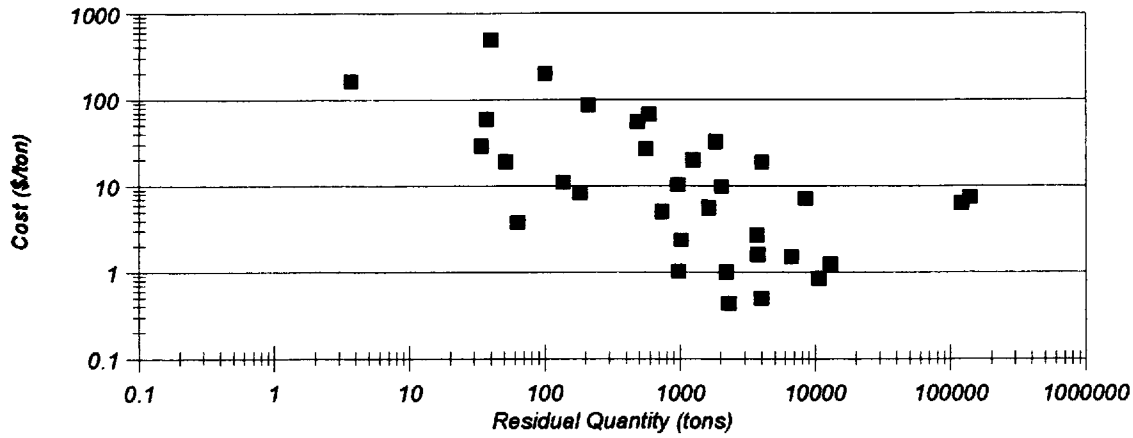


Figure 79—Offsite Management Cost for Spent Sulfidic Caustic: 1995

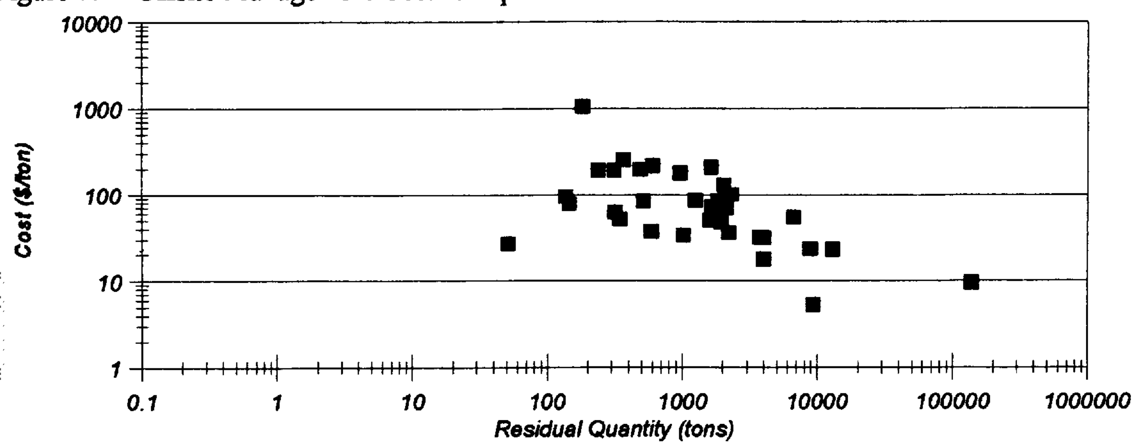
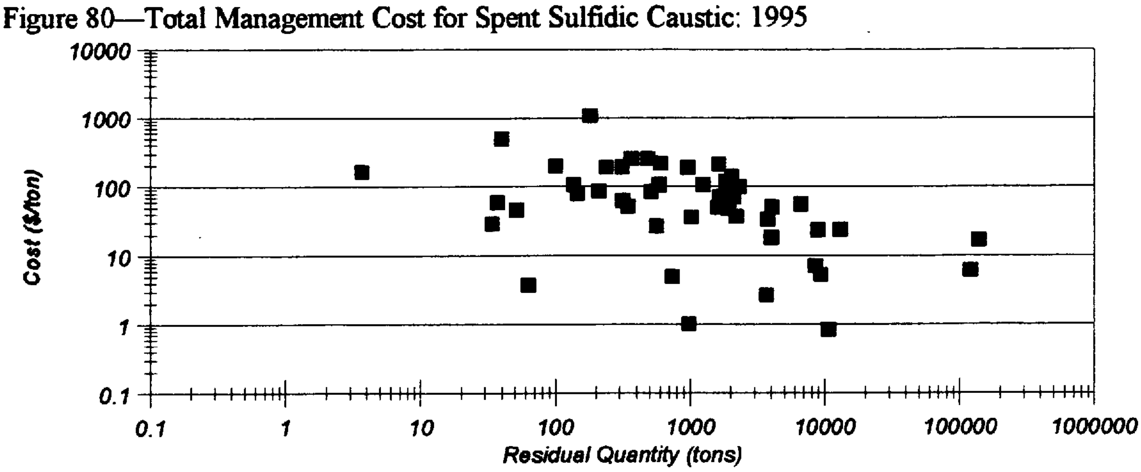


Figure 80—Total Management Cost for Spent Sulfidic Caustic: 1995



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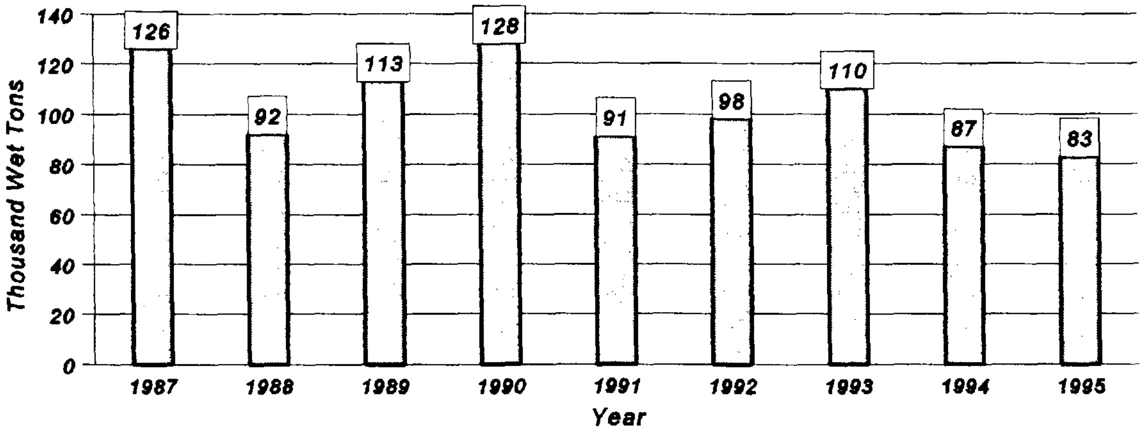
TANK BOTTOMS[14]

The U.S. petroleum refining industry managed an estimated 83 thousand wet tons of Tank Bottoms in 1995, which was a 4% reduction from 1994. A summary of the quantity of Tank Bottoms managed per year is presented in Figure 81. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

Figure 81—Nationwide Estimates of Tank Bottoms per Year: 1987-1995.



The portion of the Tank Bottoms stream that is managed by each management practice is shown in Figure 82 for 1994 and 1995. Recognizing only the actual residual stream, and not recovered oil or water, disposal continues to be the most common practice.

Figure 82—Nationwide Estimates of Tank Bottoms by Management Practice: 1994-1995.

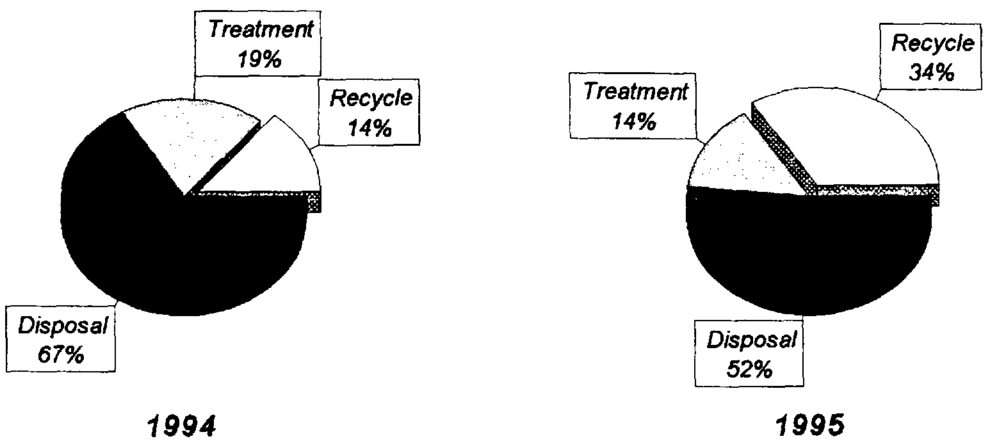


Figure 83 shows the Tank Bottoms distribution by management technique for 1994 and 1995. The quantities shown for recycling to the *crude unit* and for *wastewater* treatment have gone to zero, in that recovered oil and water from dewatering operations are not truly residuals and are no longer included. The dominant techniques used to manage this stream are to dispose of the material in a *landfill*, recycle it through a *coker*, or to manage it by *land treatment*.

---

[14]Recall that this report uses labels such as Tank Bottoms in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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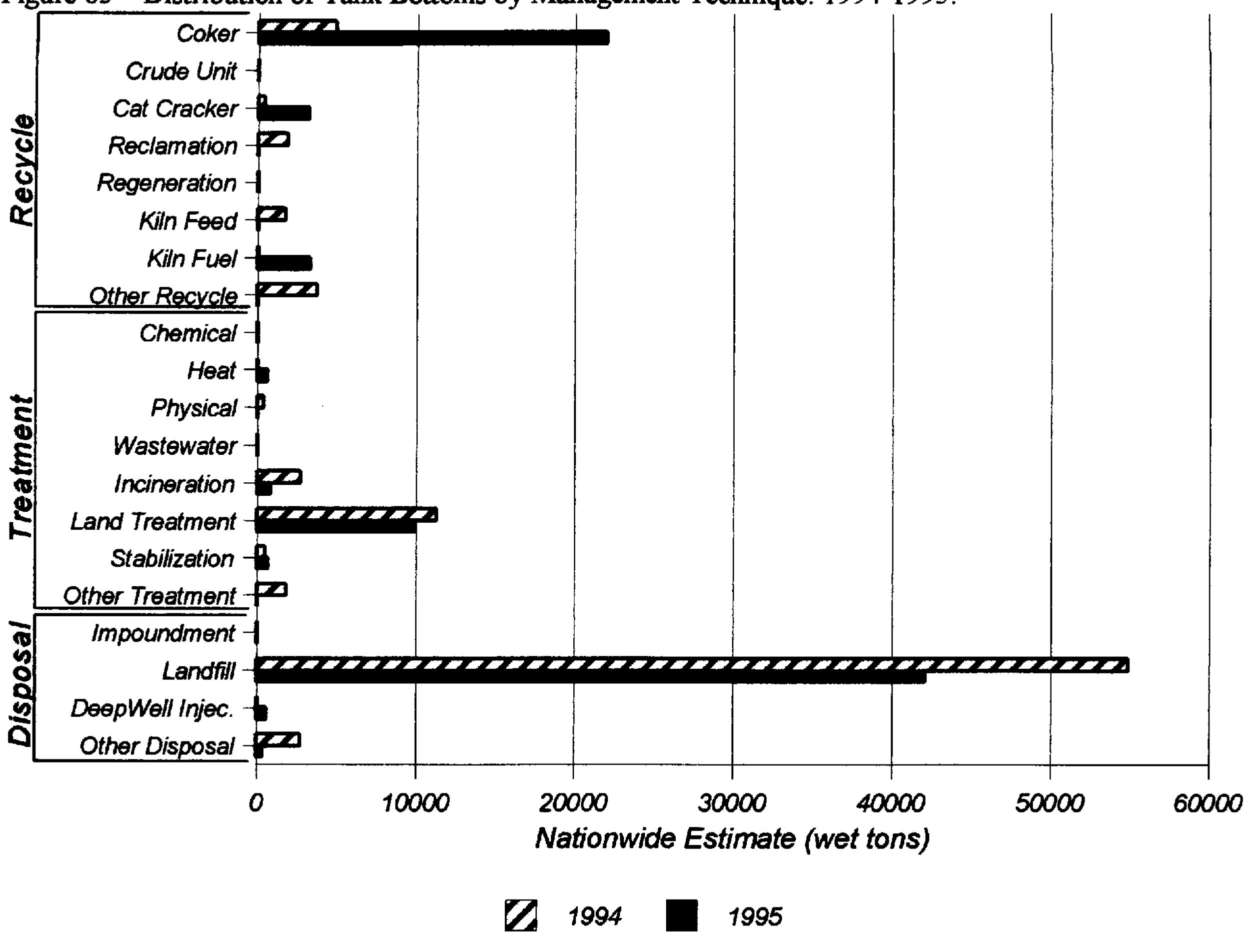
Figure 83—Distribution of Tank Bottoms by Management Technique: 1994-1995.



Responses in the *other* categories are listed below.

Other Recycle: none.

Other Treatment: none.

Other Disposal: one facility sends oily sludges to a T.S.D.F. facility for disposal.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

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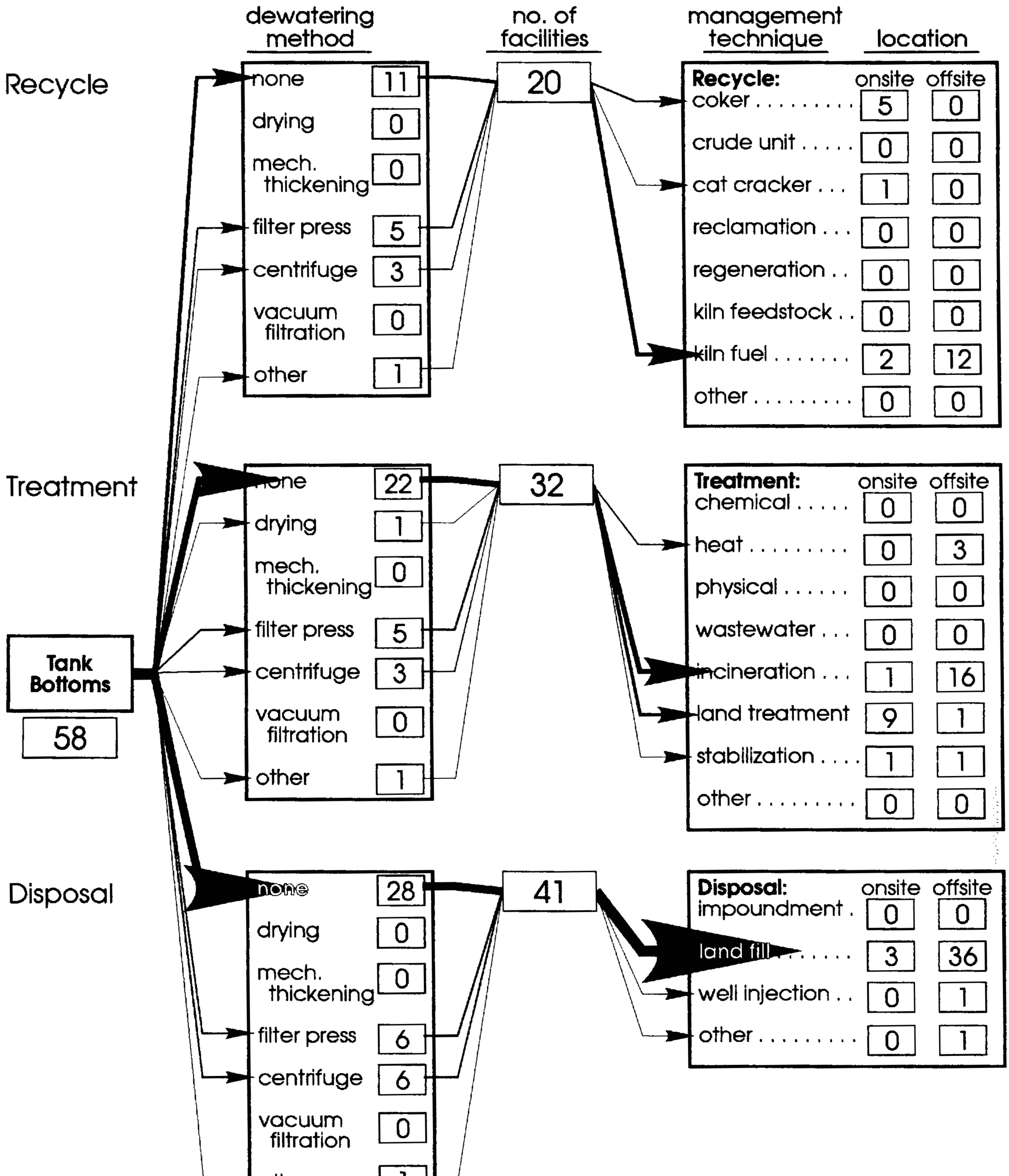
Figure 84 - Tank Bottoms Summary: 1995

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



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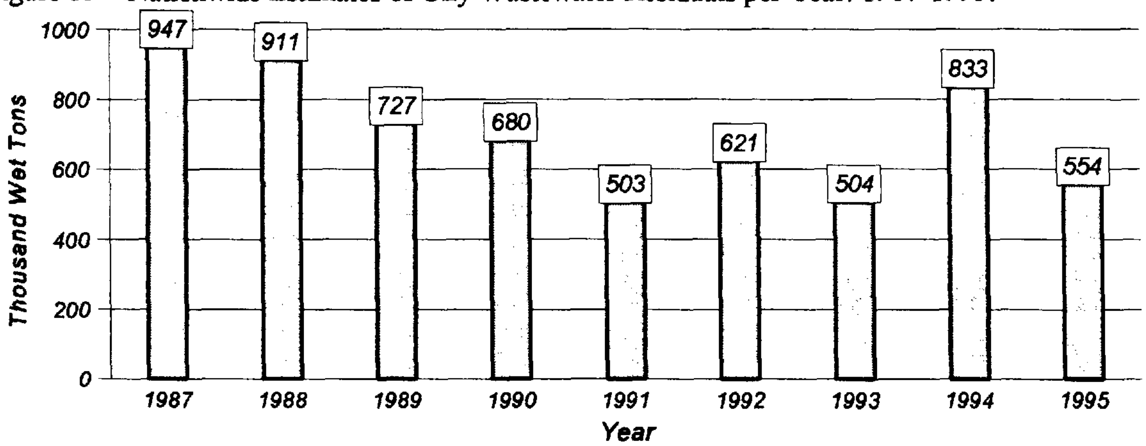
Section 4
COMBINED STREAMS

OILY WASTEWATER RESIDUALS[15]

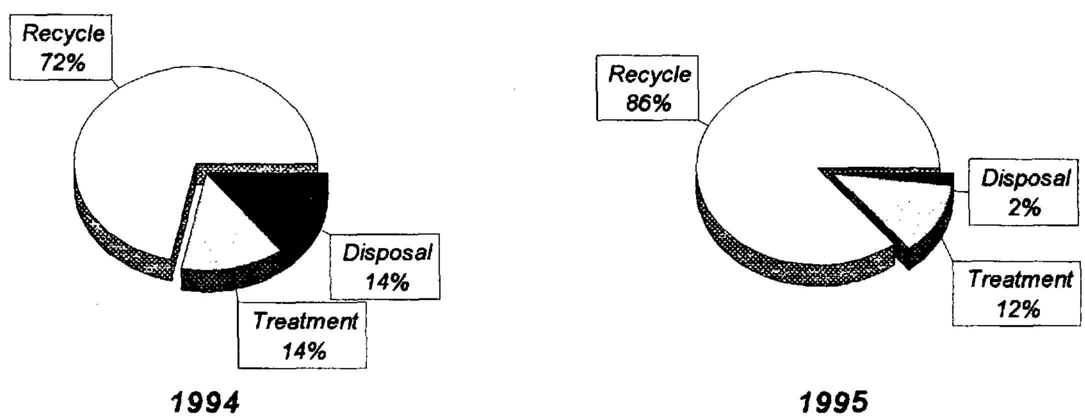
Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantity of these oily wastewater streams decreased from 833 thousand wet tons in 1994 to 554 thousand wet tons in 1995, a reduction of 33%. The combined quantities are summarized in Figure 85. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

Figure 85—Nationwide Estimates of Oily Wastewater Residuals per Year: 1987-1995.



The portion of the Oily Wastewater Residuals managed by each management practice is shown in Figure 86 for 1994 and 1995. Recognizing only the actual residual stream, and not recovered oil or water, has shown recycling to be the most common management practice.

Figure 86—Nationwide Estimates of Oily Wastewater Residuals by Management Practice: 1994-1995.



[15]Recall that this report uses labels such as Oily Wastewater Residuals in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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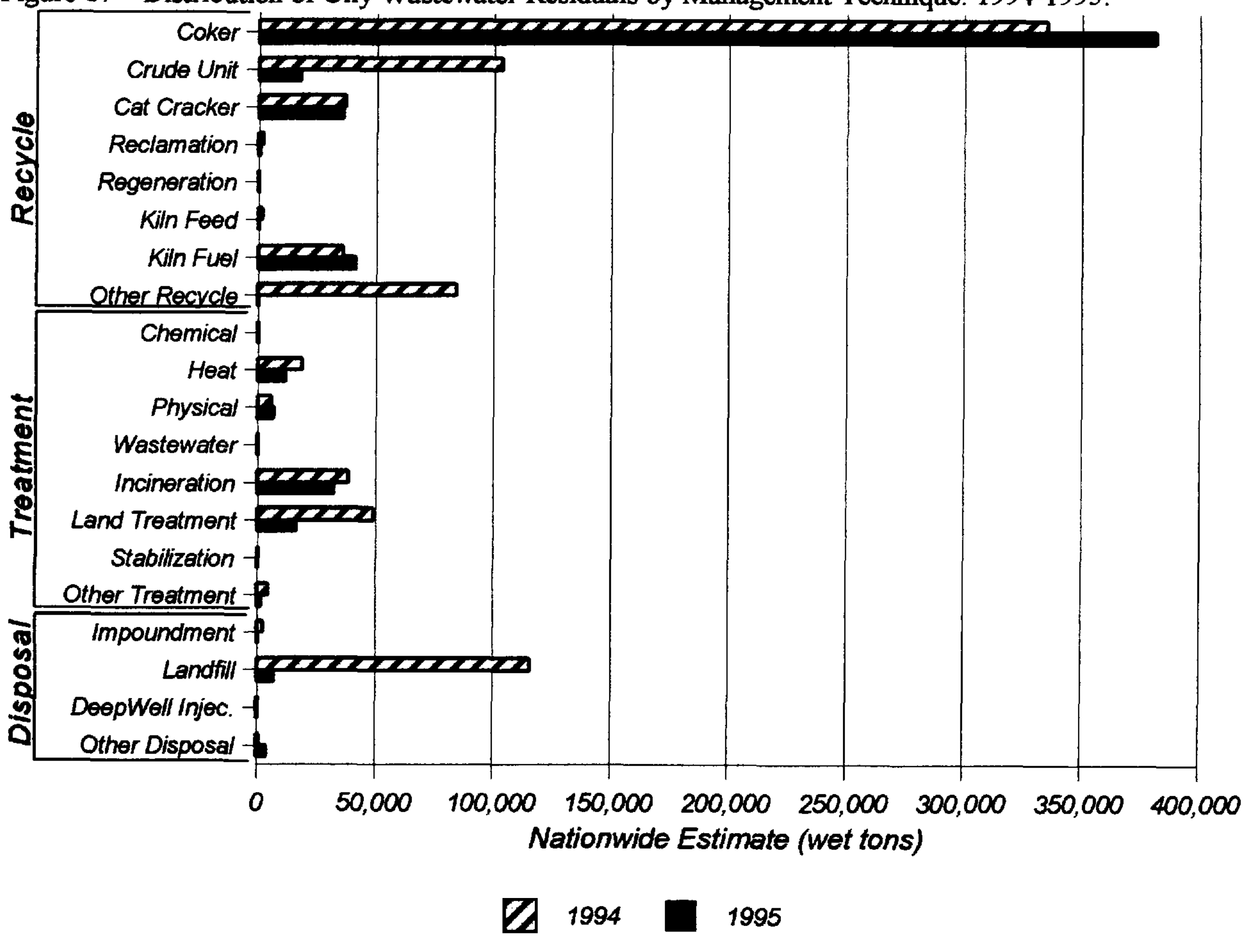
Figure 87 shows the Oily Wastewater Residuals distribution by management technique for 1994 and 1995. The quantities shown for recycling to the *crude unit* and for *wastewater* treatment have been nearly eliminated, in that recovered oil and water from dewatering operations are not truly residuals and are no longer included. The dominant technique used to manage these oily wastewater residuals is to recycle them to a process unit, most notably to a *coker*.

Figure 87—Distribution of Oily Wastewater Residuals by Management Technique: 1994-1995.



Responses in the *other* categories are listed in the sections for each of the streams that comprise oily wastewater residuals (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids).

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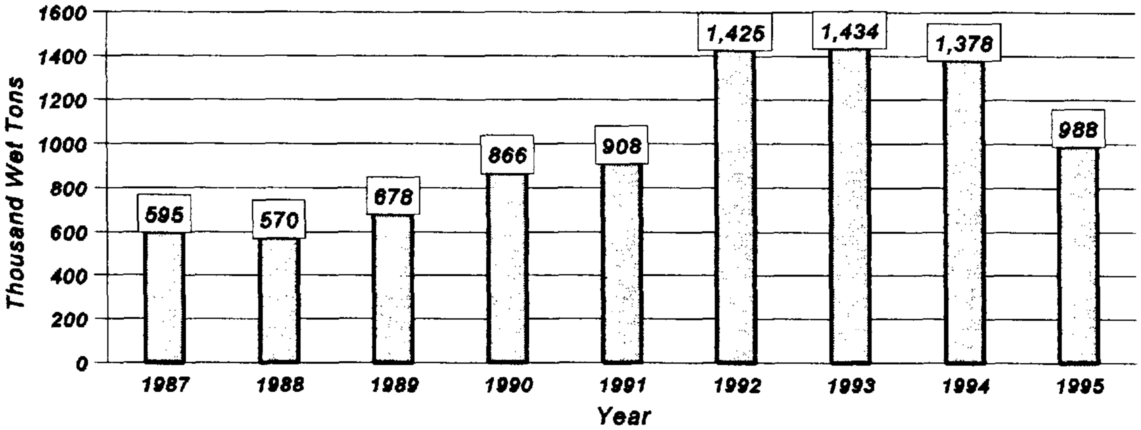
SPENT CAUSTICS[16]

The U.S. petroleum refining industry managed an estimated 988 thousand wet tons of Spent Caustics (i.e., the Spent Cresylic Caustic, Spent Naphthenic Caustic, and Spent Sulfidic Caustic streams combined) in 1995, which was a 28% reduction from 1994. A summary of the quantity of Spent Caustics managed per year is presented in Figure 88.

Figure 88—Nationwide Estimates of Spent Caustics per Year: 1987-1995.



The portion of the Spent Caustics stream that is managed by each management practice is shown in Figure 89 for 1994 and 1995. Recycling is now the most common practice.

Figure 89—Nationwide Estimates of Spent Caustics by Management Practice: 1994-1995.

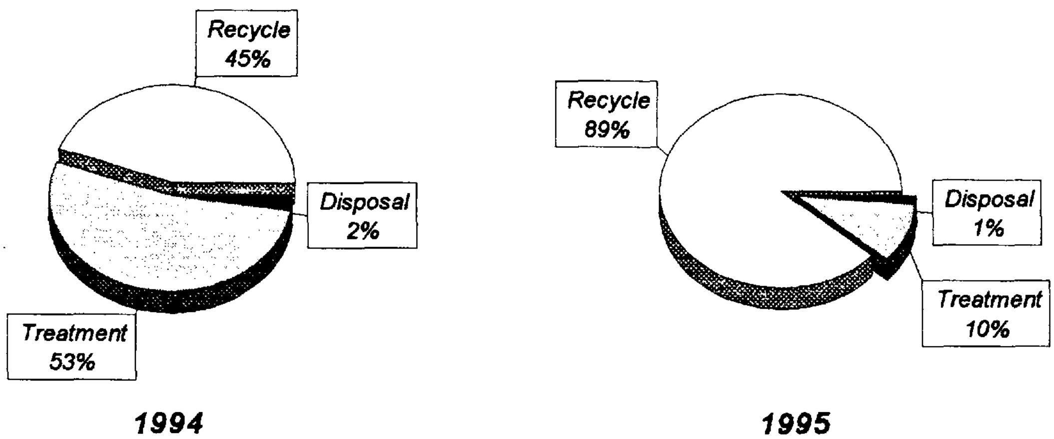


Figure 90 shows the Spent Caustics distribution by management technique for 1994 and 1995. While recycling by *regeneration* or *reclamation* are the dominant techniques used to manage Spent Caustics, there is significant variation depending upon the type of caustic. Referring back to Figures 70, 73, and 76, it is evident that it is much more common to *regenerate* spent sulfidic caustic, whereas spent naphthenic or cresylic caustics are more likely to be recycled for *reclamation*. Now that recovered water has been

[16]Recall that this report uses labels such as Spent Caustics in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

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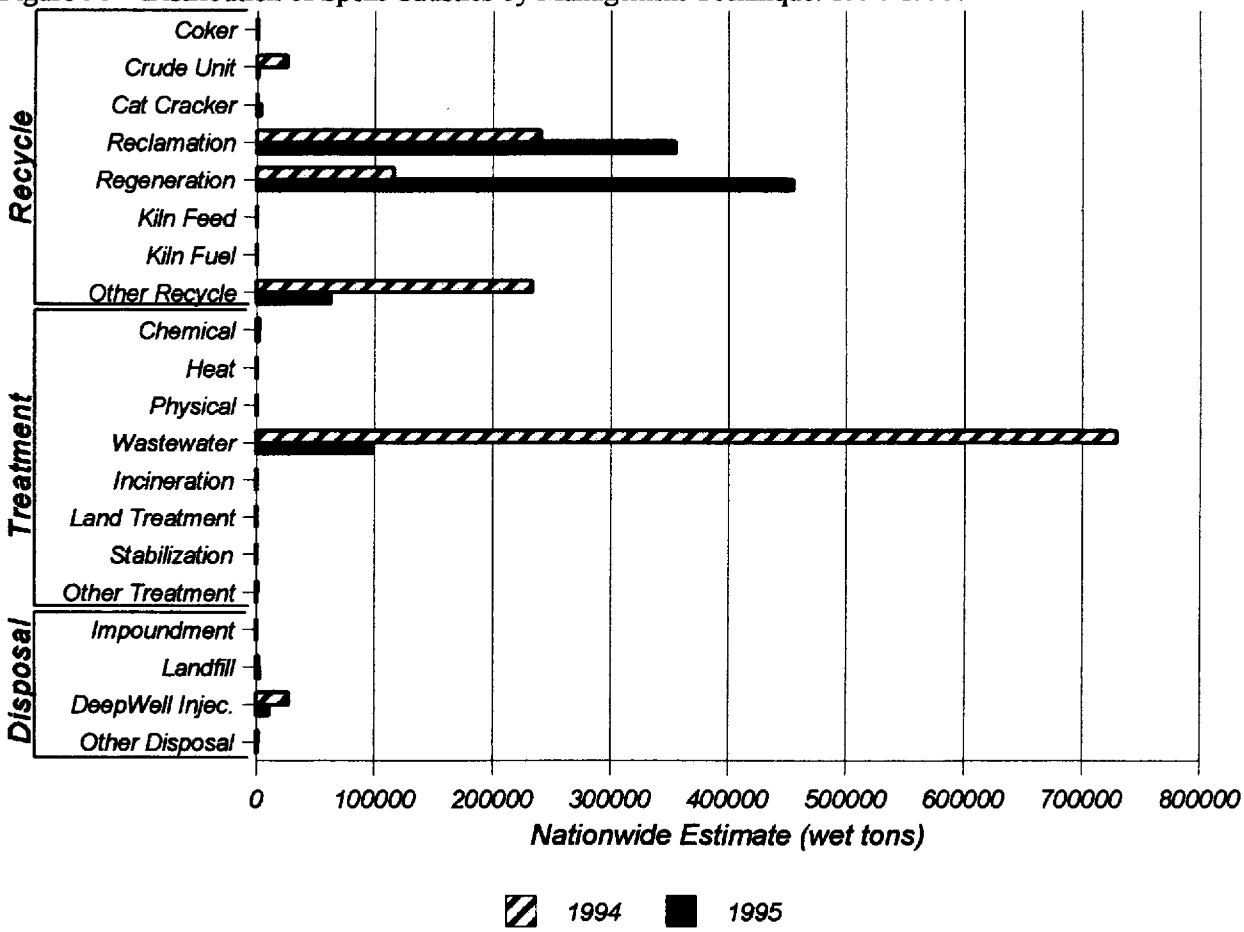
removed from the reported quantities of residuals, it is evident that the only streams that are actually managed by *wastewater* treatment are the spent caustics. Other than a small quantity of tank bottoms, spent caustics are also the only type of residual that is managed by *deep well injection*.

Figure 90—Distribution of Spent Caustics by Management Technique: 1994-1995.



Responses in the *other* categories are listed in the sections for each of the streams that comprise Spent Caustics (i.e., Spent Cresylic Caustic, Spent Naphthenic Caustic, and Spent Sulfidic Caustic).

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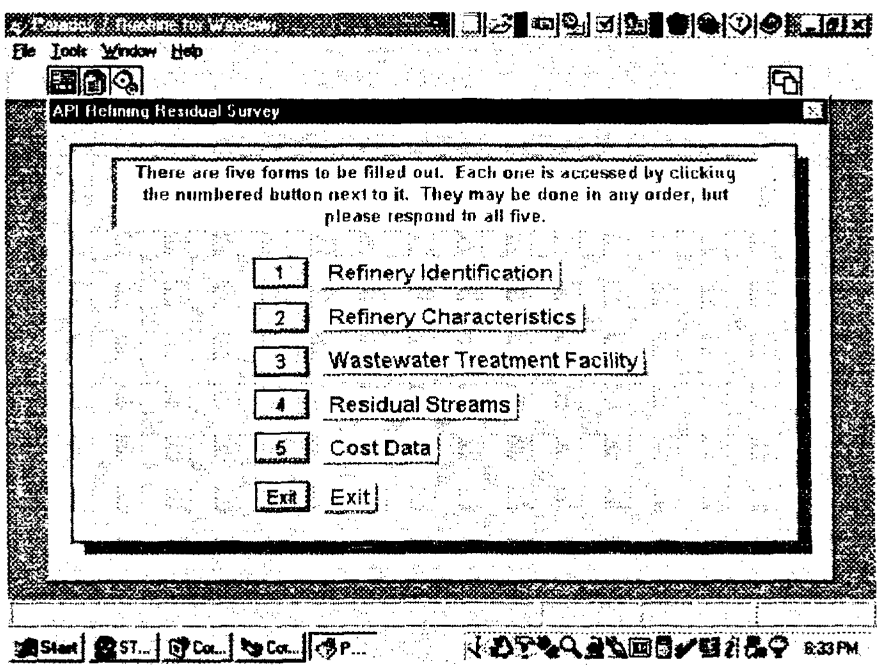
Appendix A
ELECTRONIC SURVEY FORM

The 1995 API Refining Residual Survey was distributed as a set of diskettes containing Paradox® Runtime™ and a custom Paradox® application. Paradox® Runtime™ is software that allows an end user to run custom Paradox® applications without requiring that they have Paradox® or any other application software. Both Paradox® and Paradox® Runtime™ are owned by Borland International, who allows companies registered to use both products to distribute unlimited copies of Paradox® Runtime™ on a royalty-free basis to end users in order to run custom Paradox® applications. In this instance, the registered application developer is The TGB Partnership, and the custom Paradox® application is the 1995 API Refining Residual Survey.

The custom application required the following computer system features and capabilities.

Processor	386 or higher.
Memory (RAM)	6 MB (8 MB recommended).
Hard disk	13 MB of free space.
Video monitor	VGA or higher.
Operating system	Microsoft Windows, version 3.1 or later.
Mouse	Required.

Upon loading the software, a Runtime icon group is created in the Program Manager. Double-clicking the Runtime icon results in the following menu being displayed on the screen.



The written instructions direct the user to click on a button to open a form. Completing the survey requires filling out each of the five forms. Clicking on Button 1–Refinery Identification brings up the screen shown on the next page.

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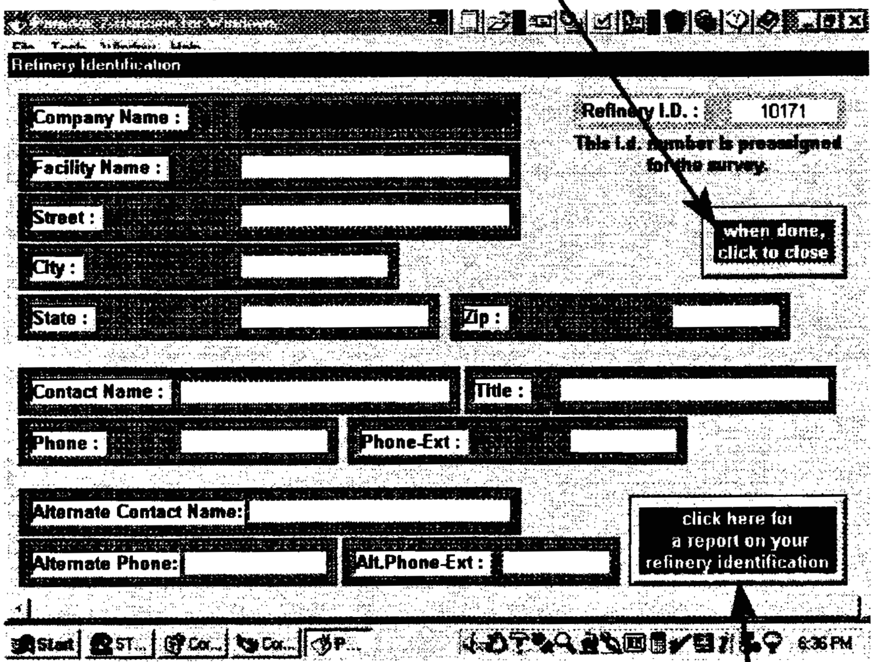
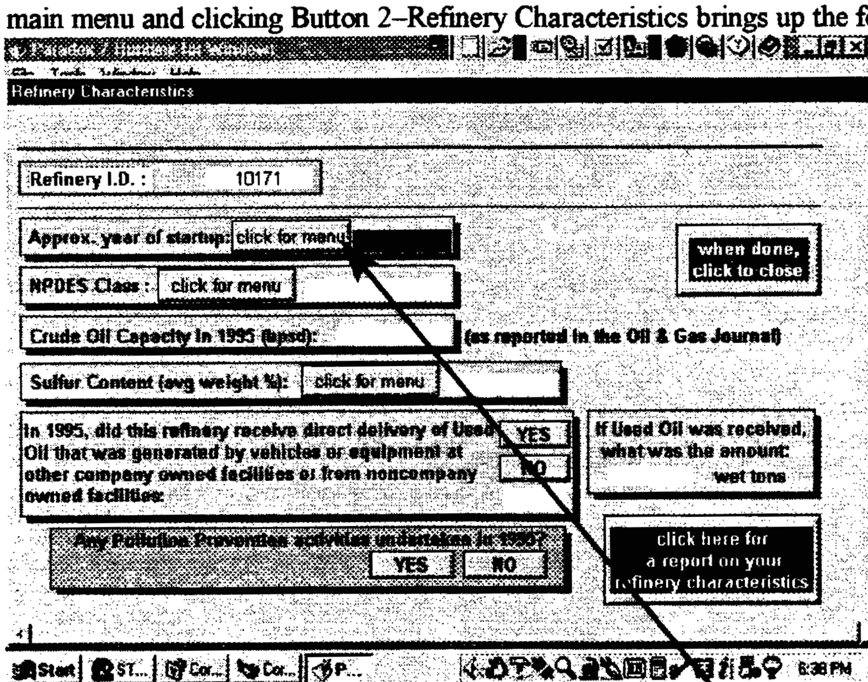
At any time, the user may return to the main menu by clicking this button. All data will be automatically saved, and can be revised by returning to this form.



Clicking this button will print a report of the data on this page.

Returning to the main menu and clicking Button 2–Refinery Characteristics brings up the following screen.



Many of the survey questions include a button that brings up a list for choosing a response.

On-screen buttons allow the user to access a list from which to choose a response. This format is handy to the user in that it does not require any particular computer skills, nor does it require searching through an instruction manual for a list. Providing a list of appropriate response choices also promotes consistent entry of data. A sample list is shown on the next screen.

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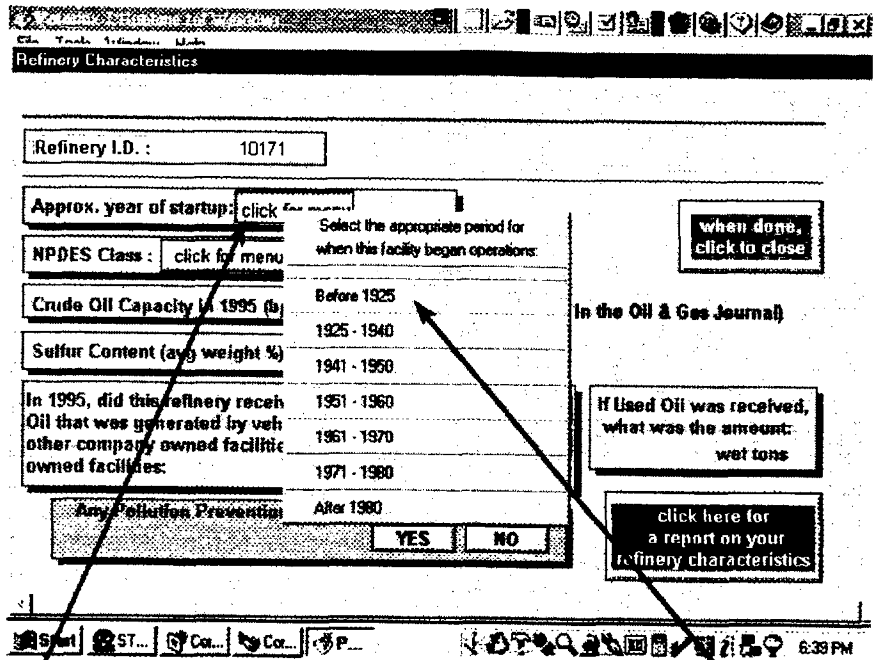
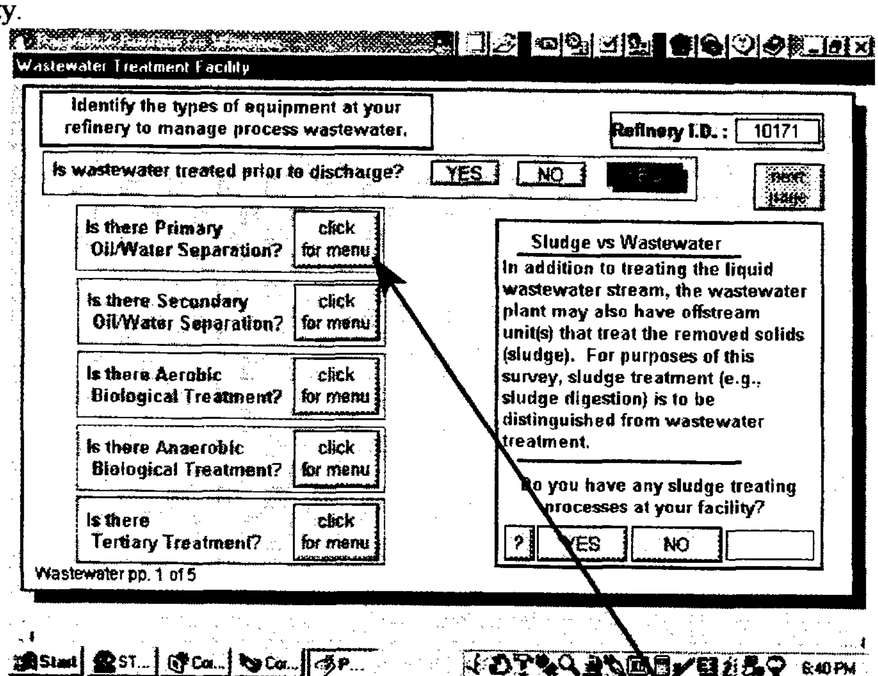


Users simply click the menu button for 'Approx year of startup', then click on the response that corresponds to the period in which their facility began operations.

The third button opens a multi-page form collecting data on the configuration of the facility's wastewater treatment facility.



For each level of wastewater treatment, there is a button to open a form containing a list of equipment.

The first page of the wastewater form requests that the user indicate the types of equipment in use at the wastewater facility. The form shows various levels of wastewater treatment, and includes a button for each. Clicking the button calls up a form containing a list of the types of equipment typical to that level of treatment. One such list is shown on the next screen.

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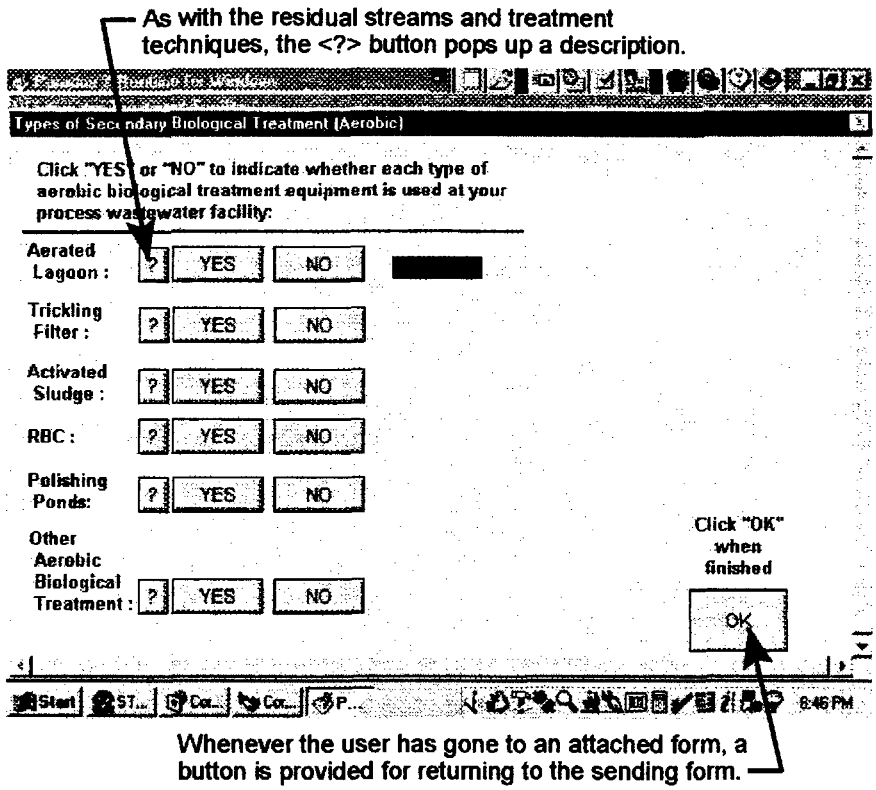
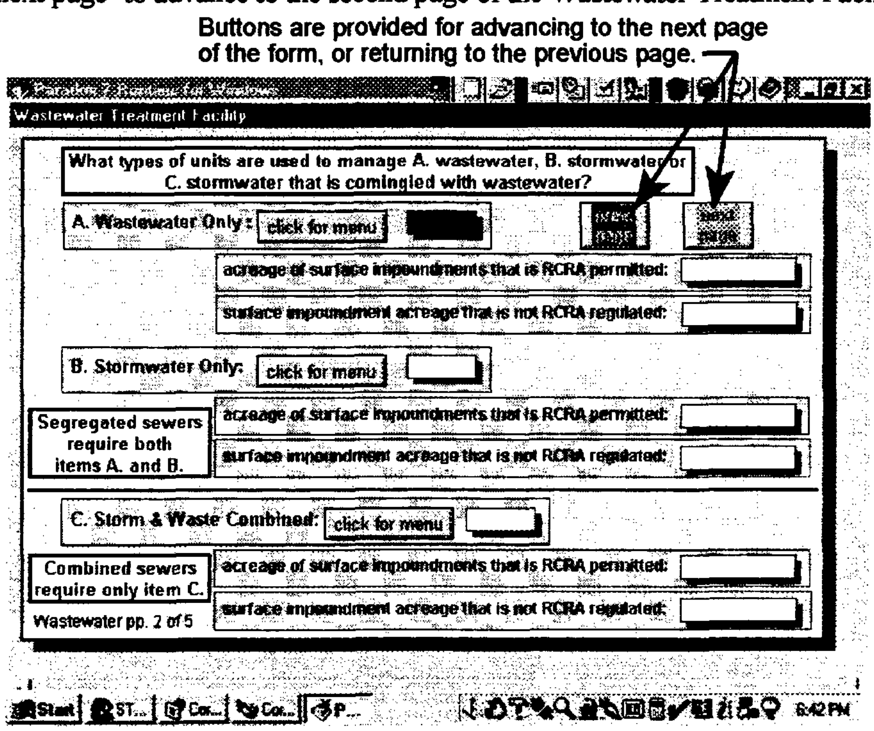


After responding to the equipment questions on the first page via its called lists, the user simply clicks the button labeled 'next page' to advance to the second page of the Wastewater Treatment Facility form.



This page collects information on the management of wastewater and stormwater. The menu buttons offer the choices of 'tanks only', 'tanks and impoundments', and 'surface impoundments only'. If the user indicates the use of surface impoundments, then the acreage is requested.

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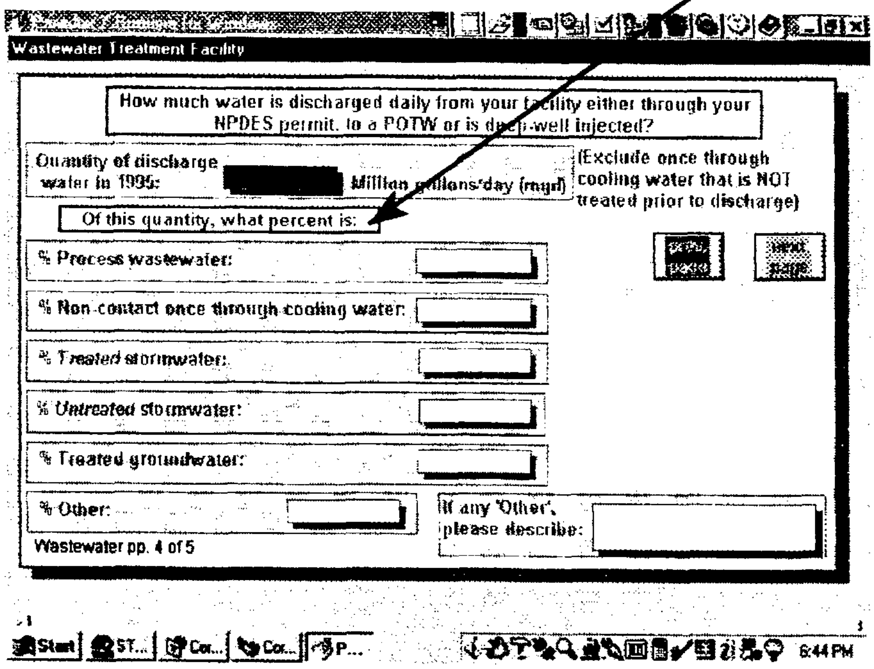
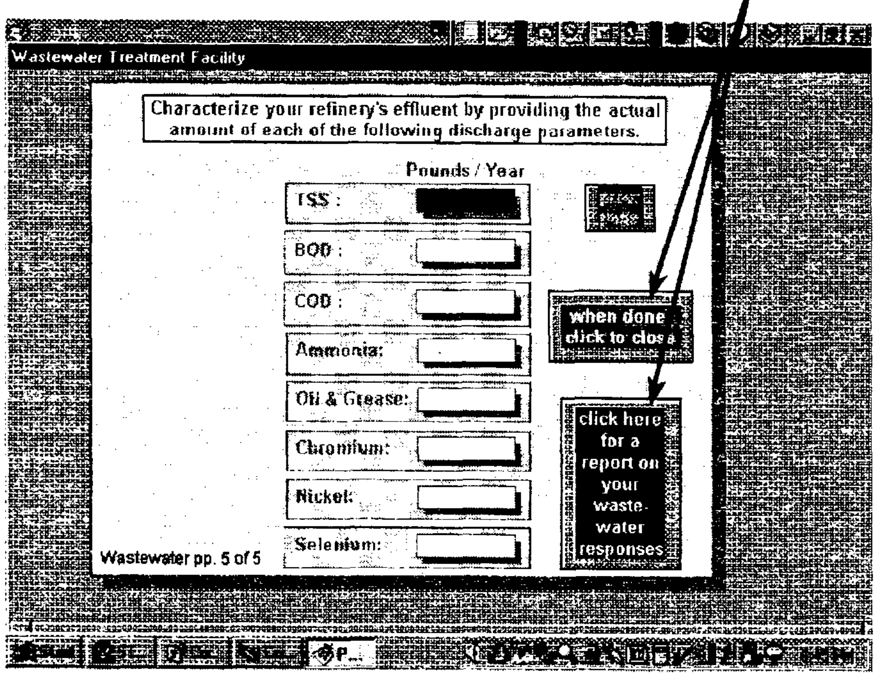
The report proceeds to collect data on the quantity and sources of the water discharged from the facility.

If the user attempts to enter a decimal fraction rather than a percent, the program will prompt a correction.



The final page of the Wastewater Treatment Facility form requests detail on the characteristics of the discharge water.

Being the last page of this form, the buttons for printing a report and for returning to the main menu are found here.



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The first three forms of the survey have collected information on the facility. Button 4–Residual Streams–opens the form that gathers the actual residuals management information. This form has a button for each residual stream in the survey, with a <?> button next to each. Clicking on the <?> button produces a pop up message with a brief description of that residual.

The 14 residual streams in the 1995 survey and the definitions assigned to each are listed below.

API Separator Sludge—the sludge that settles out by gravity in the API separator. (aka K051)
Biomass—dead bugs (microorganisms) and other sludge removed from biological treatment units. (aka BIOX sludge)
Contaminated Soils & Solids—includes materials resulting from cleanup of new spills, remediation of old spills, or excavation for construction.
DAF Float—the froth skimmed off the top of a DAF unit (the sludge on the bottom is Primary Sludge). For gas flotation units other than DAF (e.g., DNF, IAF), both the float and the sludge are primary sludges. DAF Float is RCRA listing K048.
FCC Catalyst—this includes withdrawal of equilibrium catalysts, solids drawn off from an electrostatic precipitator, and sludge from an FCC catalyst settling pond. If routed to TANKAGE for settling, however, the tank sludge should be reported as Tank Bottoms.
Hydro. Catalyst—catalysts that are used to remove sulfur, nitrogen, & metals. This residual is typically only generated when a reactor is reloaded during a turnaround. This does NOT include precious metal or raw water treating catalysts.
Other Spent Catalyst—only include other SOLID catalysts, such as precious metal or raw water treating catalysts. These are also typically generated only at turnarounds.
Pond Sediments—sludges (including underlying soils) removed from the bottom of ponds or pond sites, including ponds downstream from bio units, raw water intake ponds, and stormwater holding ponds - but NOT catalyst settling ponds.
Primary Sludges—generally any wastewater residual that is not separately classified (i.e., everything removed from the wastewater stream other than from the API Separator, bio-treatment units, or the float from DAF units). This category includes BOTH F037 AND F038.
Slop Oil Emulsion Solids—various origins, such as sludge from slop oil tanks or from tanks storing water bottom drawdown, IF containing emulsion solids. (aka K049)
Spent Cresylic Caustic—this spent caustic is typically from treating gasoline.
Spent Naphthenic Caustic—this spent caustic is typically from treating jet fuel.
Spent Sulfidic Caustic—this is spent caustic that was used for the removal of hydrogen sulfide from light-end products.
Tank Bottoms—sludge cleaned from storage tanks (including tanks storing crude oil, products - leaded or unleaded, and bottoms receiver tanks - i.e., tanks collecting the heaviest product fraction from distillation units), unless the sludge contains emulsion solids.

It should be understood that the residual stream labels used in this survey are NOT used in a regulatory sense. Whereas the Environmental Protection Agency (EPA) regulations implementing RCRA have given these terms special meaning, the usage here is in a broader, more generic sense. API's intent is to have survey participants report the management of all residual type materials (e.g., materials that are byproducts or residuals of petroleum refining operations). This includes residuals that are beneficially recycled or reclaimed, as well as materials that are discarded.

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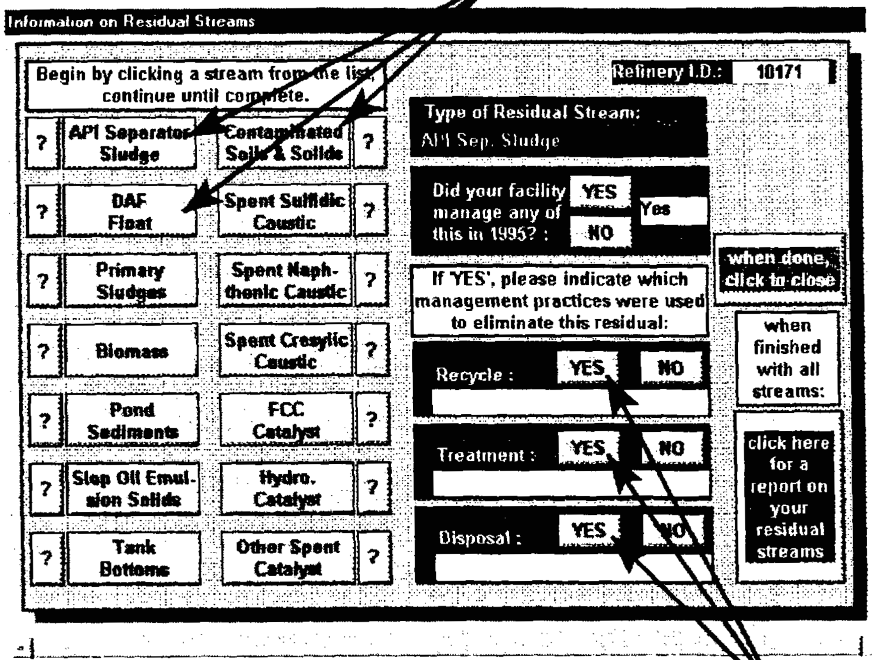
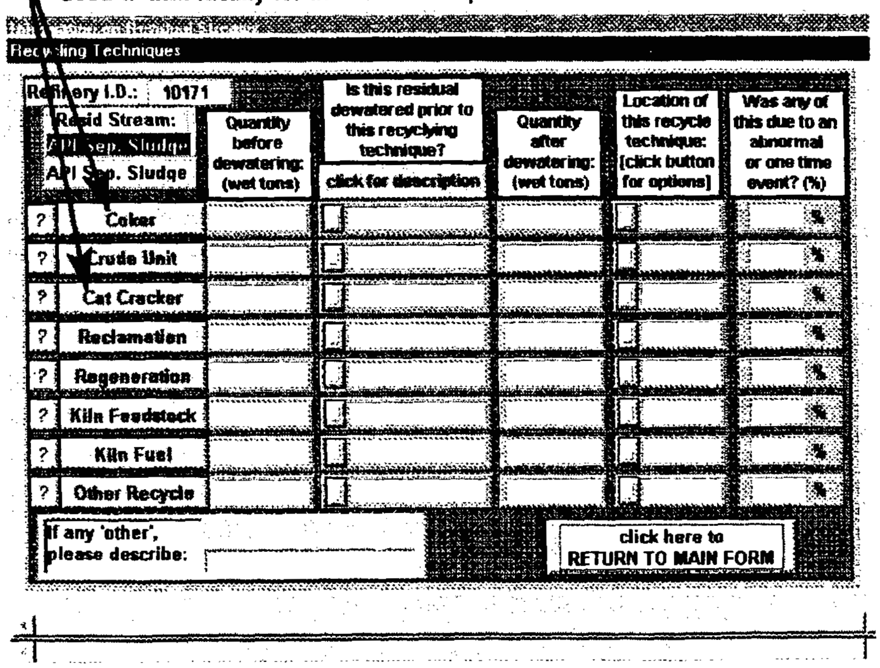
The user selects each stream in turn, and answers the questions for that stream.



Clicking <YES> for a management practice brings up a menu of that practice's management techniques.

Clicking a button with a stream name makes it the active stream in the form, and the user then fills in the information for it. Clicking <YES> for any of the management practices calls a form listing management techniques, with the currently selected stream active. When a form for a selected management practice is first called for a particular stream, it has no data. After data have been entered and the form has been exited, the data can be revised by selecting that stream and again clicking <YES> for that management practice. The called form will reappear, but will now show the data entered previously.

The user fills out the information for each technique used at that facility for the stream in question.



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The management techniques from the 1994 and 1995 surveys are listed below, with the definitions assigned to them for the 1995 survey.

Recycle

Coker—this refers to routing the residual back to the coker, which is a thermal cracking unit (i.e., no catalysts).

Crude Unit—this refers to routing the residual back to a crude unit, which is an atmospheric or vacuum distillation unit.

~~Desalter~~—zero responses for this technique in 1994; deleted from the 1995 survey form.

Cat Cracker—this refers to routing the residual back to a cat cracker, which is any cracking unit that uses a catalyst.

Reclamation—this refers to the extraction of oil or other usable material from the residual. If the residual is restored to its original use, however, then it is classified as Regeneration.

Regeneration—restoring residual material so that it may be returned to its original use (typically applied to catalysts); this also applies to the oxidation of spent caustics IF resulting in reusable caustic (even though it also involves reclamation of oil).

Cement Kiln Feedstock—this applies if the residual is used as raw material (rather than for fuel) at a cement kiln.

Cement Kiln Fuel—this applies to residuals that are sent to cement kilns to be used as fuel.

~~Other In-Process Recycle~~—all Other Recycle combined into one category in the 1995 survey.

~~Other Out-of-Process Recycle~~—ditto.

~~Other Industrial Fuel Reuse~~—ditto.

Other Recycle—this applies to any recycling technique not listed above.

Treatment

~~Weathering~~—zero responses for this technique in 1994; deleted from the 1995 survey form.

Chemical—this involves the addition of chemicals for the purpose of treatment, such as flocculant to settle out solids from emulsions.

Heat—medium to high heat methods (e.g., hot oil, electric drier, rotary kiln) are classified as Heat Treatment. Use of low heat, such as steam, is classified as Dewatering and NOT as Heat Treatment.

~~Impoundment~~—zero responses for this technique in 1994; deleted from the 1995 survey form.

Physical—this is gravity separation; i.e., settling out into oil, water, and solid phases by standing in a tank for an extended period of time.

Wastewater Treatment—this applies to residuals that are routed to wastewater, typically through the sewer. Do NOT include material sent to the sludge digester, to sludge thickening, or liquids returned to the wastewater stream from dewatering operations.

Incineration—this applies to enclosed combustion, and typically requires auxiliary fuel.

Land Treatment—this includes any landspreading or landfarming operation. The residual may be broadcast onto the ground or injected just under the surface, and may involve subsequent activities to promote biodegradation, such as tilling, watering, or fertilizing.

Stabilization—this applies to solidification with agents such as lime or cement for purposes of reducing leachability.

Other Treatment—this applies to any treatment technique not listed above.

Disposal

Impoundment—this refers to placing the residual in a depression in the ground or in an area diked with an earthen material (e.g., a pit, pond, or lagoon). This does NOT apply to settling or bio

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ponds, which are Treatment techniques.

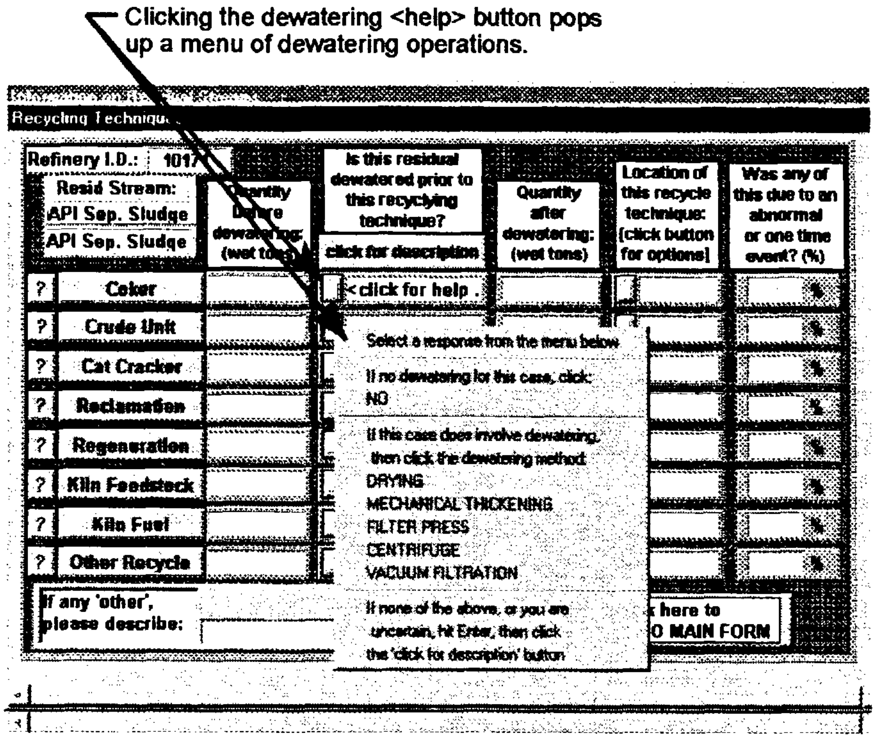
Landfill—this applies to material that is collected in or on the ground and covered. It typically involves only nonflowing residual material.

~~Landspread~~—combined with Land Treatment in the 1995 survey.

Injection—changed to Well Injection in the 1995 survey; this applies to injection into a deep well which would typically extend into a nonporous rock formation. Surface injection is classified as Land Treatment.

Other Disposal—this applies to any disposal technique not listed above.

The form that is called by selecting a management practice includes a question on the type of dewatering operations used, if any. This question is repeated for each management technique listed on the form. As with most other non-numerical queries, a pop up menu is provided to facilitate the response.



The <click for description> button under the dewatering question calls a form with the dewatering operations listed. Clicking on the button with the name of a dewatering operation pops up a menu with a description of that operation, as shown on the next screen.

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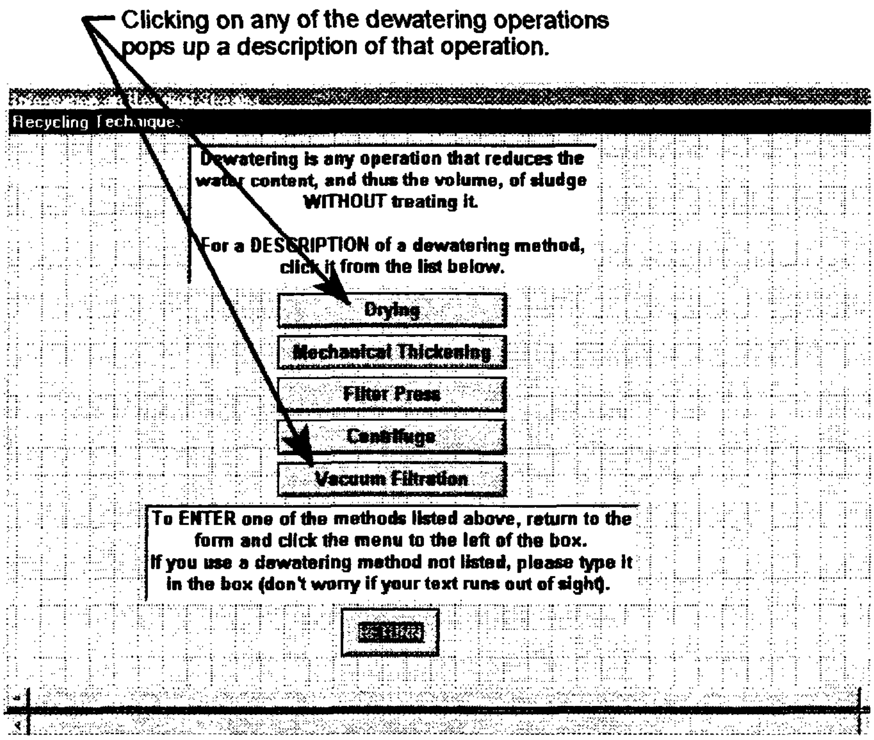
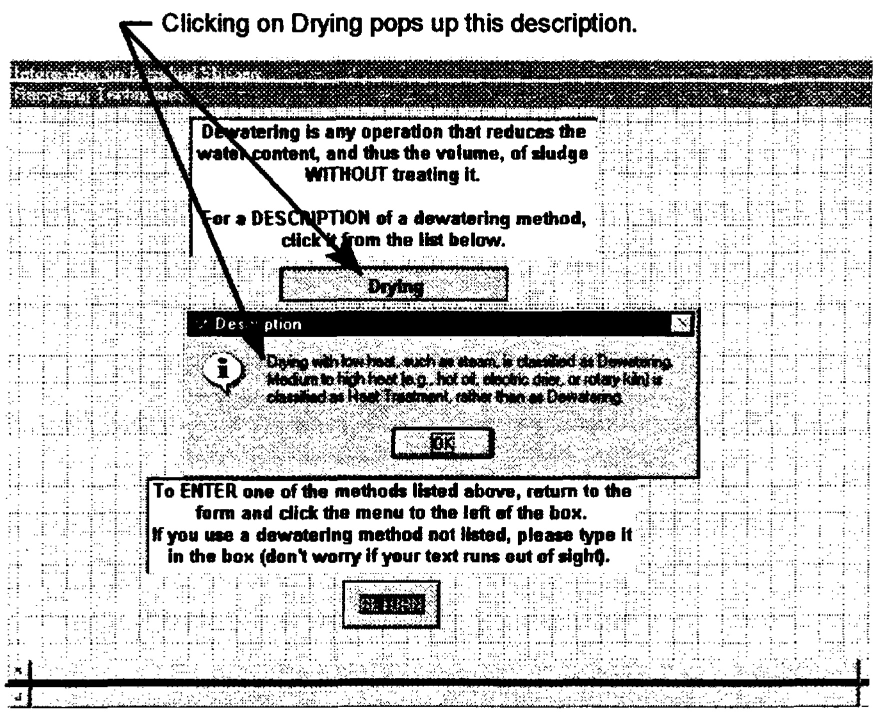


A sample definition is shown on the following screen.



The final form of the survey is activated by clicking Button 5–Cost Data. This form is similar in appearance to the Residual Streams form, but contains 6 streams rather than 14, as shown on the following page.

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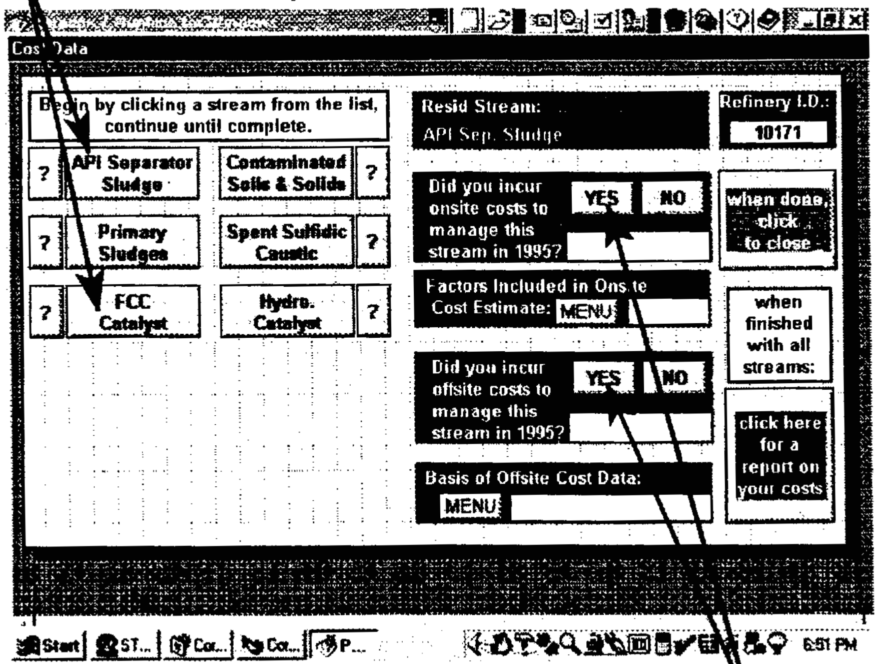
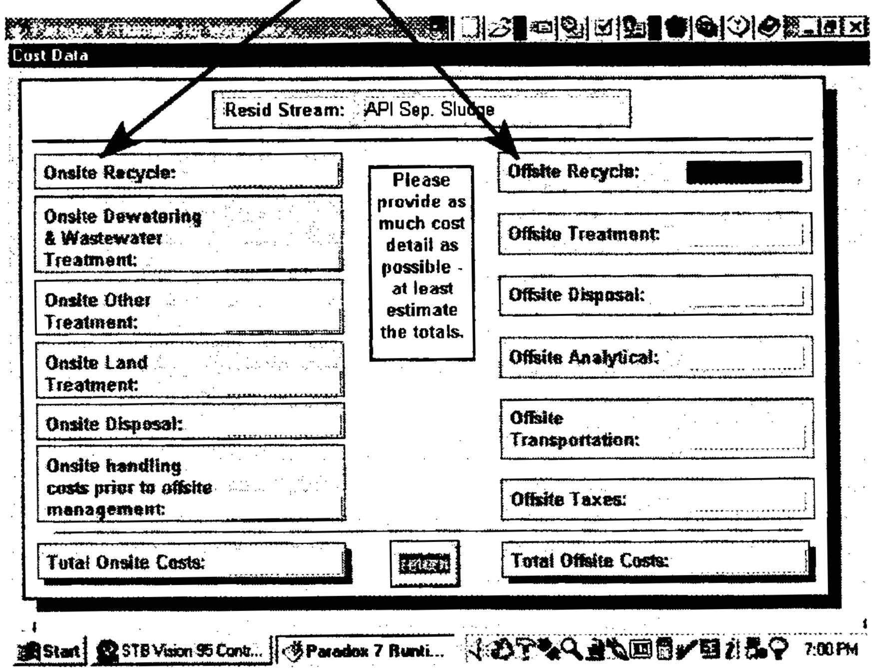
The Cost Data form is similar to that for Residual Streams, but lists only six streams.



Clicking the <YES> button calls a form with boxes to enter cost data.

Clicking <YES> for either the onsite or offsite cost question calls a form for entering the cost data.

Separate columns are provided for onsite & offsite costs.



The user may return to any form or page and edit the entries. After completing the survey, the respondent copies the directory to a diskette and mails it to API.

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Appendix B
DESCRIPTION OF STATISTICAL PROCEDURES

The 1995 API Refining Residual Survey used similar statistical analysis methods as used in previous years. No changes were made in the procedures for generating the regression model, extrapolating the respondent data to nationwide estimates, or in estimating nationwide quantities for the individual residual streams. This was done to maintain consistency in the reporting methods from year to year. Some of the specific statistical checks, however, were deleted from the analysis.

DATA COLLECTION

The 1995 survey was the first to require electronic submission of data. While this impacted the mechanics of compiling the data, it required no change in the procedures used to analyze the data.

It was observed that a certain amount of the variance in previous surveys was attributable to inconsistency in the assumptions made by respondents. Quantities had varied depending upon whether a facility reported the amount of residual before dewatering, or only the sludge cake remaining after dewatering. Furthermore, the assignment of categories had varied due to differing interpretations of the meaning of certain survey terms. To promote consistency, the 1995 survey included explicit instructions to report only the quantity of residual remaining after dewatering, exclusive of recovered oil or water. Another step taken to facilitate consistency was to add a pop up message box for each category in the survey, containing a definition of the label for that category. The elimination of wastewater treatment as a listed management technique from every stream except the spent caustics is an indication that the revised instructions resulted in more uniform responses.

Data were collected on the same 15 residual streams as in the 1994 survey, but combining the two primary sludge categories resulted in 14 streams in the 1995 survey. The 15 streams in the 1994 survey were only half the 30 streams included in earlier surveys, but those 15 streams represented approximately 80% of the total residual quantity from the previous surveys. The 1994 report concluded that the data pattern had changed very little with the fewer streams, and the regression model used previously was retained. In that the 1995 survey collected data on the same streams as in 1994, the same regression model was used again.

REGRESSION MODEL

In order to generate an estimate of the total quantity of residuals managed nationwide, a model must be developed for predicting the quantity of residuals managed at the facilities which did not respond, based on the data received from those refineries that did respond. The development of this model involves establishing the relationship of some known quantity to the unknown quantity of residuals. In each year of the API Refining Residual Survey, the known quantity of throughput capacity has been used to predict the unknown quantity of residuals managed. The model assumes a linear relationship between throughput capacity and the square root of the total quantity of residuals managed, as shown in the following equation.

$$\sqrt{R} = b_0 + b_1 C$$

Where:
- R = estimate of total residuals managed by a facility (wet tons),
- b_0 = the y-intercept of the regression line,
- b_1 = the slope of the regression line, and
- C = the throughput capacity of the facility (bsd).

The value of R is described as an estimate of the total quantity of residuals managed by a refinery, but in fact is now taken as the total of those streams included in the survey. Given this revised definition of R,

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which was first introduced in the 1994 survey, throughput capacity continues to be an acceptable predictor of the square root of residual quantity. The known value of throughput capacity was taken as that published by the Oil & Gas Journal in the table, *Worldwide Refineries-Capacities as of January 1, 1995.*

FITTING THE MODEL TO THE 1995 DATA

Data from the 74 respondents to the 1995 survey were plotted on a scale of $R^{0.5}$ versus C and compared to several other trial relationships as a test of the appropriateness of the model. The other trials included a linear relationship of R and C, and a linear relationship of log(R) versus log(C). A linear regression of the data was performed for each model, using the method of least squares, and the $R^{0.5}$ versus C model was found to still result in the best fit.

The 1994 survey had excluded the larger facilities from the data for the linear regression, but all 74 facilities that responded to the 1995 survey were included in the data base for the regression analysis.

The equation developed from the 1995 survey is:

$$\sqrt{R} = 31.913 + 7.888\times10^{-4}C$$

with an R^2 measure of correlation equal to 0.70, which is an improvement over the correlation of 0.59 determined for the 1994 survey.

INDUSTRY ESTIMATES

The industry estimates were determined in the same manner as in previous years. First, the throughput capacity was determined from the Oil & Gas Journal table for each facility that did not respond. This value was then input as C in the regression equation to calculate an estimated value of R for that facility. The square root of a quantity, however, is a biased estimator and thus requires a correction factor to yield an unbiased estimate. After the bias correction was made to each facility estimate, the nonrespondent quantities were summed and added to the sum of the respondent quantities. This yielded the total residual estimate for the U.S. petroleum refining industry. The reliability of this estimate can be stated as a percent error. Both the bias corrections for the individual estimates and the percent error for the nationwide estimate are explained below.

ESTIMATING NONRESPONDENT QUANTITIES

Biased Estimate

A biased estimate of the quantity of residuals managed by each nonrespondent facility is calculated from the regression equation:

$$\sqrt{R} = 31.913 + 7.888\times10^{-4}\,C$$

And then:

$$R = \left(\sqrt{R}\right)^2$$

In order to illustrate this determination, assume a throughput capacity of 72,000 bsd:

$$\begin{aligned}\sqrt{R} &= 31.913 + 7.888\times10^{-4}\,(72{,}000)\\ &= 88.707\\ R &= (88.707)^2\\ R &= 7{,}869\end{aligned}$$

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Bias Correction

The bias correction factor is derived from the following relationship:[1]

$$V(\sqrt{R}) = E(R) - [E(\sqrt{R})]^2$$

where V is the variance and E is the expected value. Rearranging the above equation to solve for $E(R)$ and using R^* to represent $E(R)$, the expected or unbiased value, the following equation is obtained:

$$E(R) = [E(\sqrt{R})]^2 + V(\sqrt{R})$$

$$R^* = R + V(\sqrt{R})$$

The variance, $V(\sqrt{R})$, in the above equation is calculated from the equation[2] below for an individual nonrespondent facility h. This equation represents the variance of a new observation, independent of the values from which the regression analysis is based.

$$V(\sqrt{R_h}) = MSE\left[1 + \frac{1}{n} + \frac{(C_h - \bar{C})^2}{\sum_{i=1}^{n}(C_i - \bar{C})^2}\right]$$

Where: C_h = the throughput capacity of nonrespondent facility h,
C_i = the throughput capacity of respondent facility i,
$\bar{C}$ = the average of the throughput capacities of the respondent facilities,

And the mean square error, MSE, is determined as follows:

$$MSE = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-2} = \frac{195{,}763}{72} = 2719$$

Where: y_i = $\sqrt{R}$ as reported for respondent facility i, and
$\hat{y}_i$ = $\sqrt{R}$ as predicted for the same facility, from the regression equation.

The average capacity of the respondent facilities is 111,582 bsd and the sum of the squares equals 720,802,554,993. The bias correction factor for the illustration of 72,000 bsd is then calculated as follows:

$$V(\sqrt{R_h}) = 2719\left[1 + \frac{1}{74} + \frac{(72{,}000 - 111{,}582)^2}{720{,}802{,}554{,}993}\right]$$

$$= 2{,}762$$

The unbiased residual estimate is then the sum of the biased estimate plus the bias correction factor:

$$R^* = R + V(\sqrt{R})$$

$$R^* = 7{,}869 + 2{,}762$$

$$= 10{,}631 \text{ wet tons.}$$

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[1]Meyer, Paul L., 1970, *Introductory Probability and Statistical Applications*, 2nd ed., Addison-Wesley Publishing Company, Reading, Massachusetts, pp. 134-135.

[2]Neter, John and William Wasserman, 1974, *Applied Linear Statistical Models: Regression, Analysis of Variance, and Experimental Design*, Richard D. Irwin, Inc., Homewood, IL, pp. 69-74.

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Variance of the Unbiased Estimate

Each residual estimate for a nonrespondent has a variance associated with it. This variance is the variance of the unbiased estimate which is different from the variance of the square root of the biased value discussed previously (i.e., the bias correction factor). The variance of the unbiased estimate, based on the equation for R^*, is:

$$V(R^*) = V(R) + V\left[V\left(\sqrt{R}\right)\right]$$

The first term in the above equation, $V(R)$, is the variance of R and can be derived from the following relationship:[3]

$$V(R) \approx \left[\frac{\partial R}{\partial\sqrt{R}}\right]^2 V\left(\sqrt{R}\right) = \left[\frac{\partial\left(\sqrt{R}\right)^2}{\partial\sqrt{R}}\right]^2 V\left(\sqrt{R}\right)$$

$$= \left[2\sqrt{R}\right]^2 V\left(\sqrt{R}\right)$$

$$= 4R \times V\left(\sqrt{R}\right)$$

The second term is the variance of a variance. If σ^2 represents a variance, then the variance of σ^2 is:[4]

$$V\left(\sigma^2\right) = \frac{2\sigma^4}{n-1}$$

Rewriting the above equation in terms of R, the second term becomes:

$$V\left[V\left(\sqrt{R}\right)\right] = \frac{2\left[V\left(\sqrt{R}\right)\right]^2}{n-1}$$

Putting the first and second terms together, the variance of the unbiased estimate can now be stated in terms of the biased estimate and the bias correction factor (both of which were determined previously) as:

$$V(R^*) = 4R \times V\left(\sqrt{R}\right) + \frac{2\left[V\left(\sqrt{R}\right)\right]^2}{n-1}$$

For the illustration of a 72,000 bsd facility, the biased estimate was 7,869 and the bias correction factor was 2,762, and thus the unbiased estimate of the residual quantity is 10,631 wet tons. The variance of the unbiased estimate is therefore:

$$V(R^*) = 4(7{,}869)(2{,}762) + \frac{2(2{,}762)^2}{74-1}$$

$$= 87{,}145{,}716$$

This variance is considerably less than the value of 140,155,624 determined for the same illustration in the 1994 survey report.

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[3]*Op. cit.*, *Introductory Probability and Statistical Applications*, pg. 139.

[4]Bury, Karl V., *Statistical Models in Applied Science*, Wiley-Interscience, New York, pp.249-250.

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ESTIMATES FOR THE U.S. PETROLEUM INDUSTRY

Estimated Nationwide Total Residuals

The estimated total quantity of residuals for the U.S. petroleum refining industry is the sum of the residual quantities reported by the respondent facilities plus the unbiased estimates for the nonrespondent facilities. The total quantity reported by the respondent facilities was 1,708,451 wet tons, resulting in an estimate of 1,340,324 for the nonrespondent facilities. The total nationwide estimate of the quantity of these residual streams for the petroleum refining industry is therefore 3,048,776 wet tons.

Variance of the Total Result

The variance of the total estimated quantity is the sum of the variances associated with each individual facility. As in previous years, this calculation was simplified by assuming that the residual quantities of the respondents are known quantities which have no variance. Therefore, only the nonrespondents contribute to the variance of the total estimate. Since the total residual quantity for the industry, T, is a linear combination (sum) of the individual facility quantities, the total variance is calculated by the following equation:[5]

$$V(T) = V(R_1^*) + V(R_2^*) + \ldots + V(R_n^*) = \sum_{h=1}^{n} V(R_h^*)$$

Where:

$V(R_h^*)$ = the variance of the unbiased estimate for nonrespondent facility h, and n is the number of nonrespondent facilities.

The sum of the variances of the unbiased estimate for the nonrespondent facilities for the 1995 survey is 12,833,574,260.

Percent Error for the Estimate of Total Residuals

The percent error is based on the prediction interval for the estimate of total residuals, which is dependent upon the total variance and the confidence level chosen. For a 95% confidence level, the prediction interval is calculated by the following equations:[6]

$$T_U = T + 2\sqrt{V(T)}$$

$$T_L = T - 2\sqrt{V(T)}$$

where T_U and T_L are the upper and lower limits, respectively. Using the above equations, the prediction interval for the total industry is 2,822,206 to 3,275,347 wet tons.

The percent error, $E\%$, is then expressed as:

$$E\% = \frac{2\sqrt{V(T)}}{T} \times 100\%$$

The percent error for the 1995 estimate is 7.43%.

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[5]Box, George E.P., William G. Hunter, and J. Stuart Hunter, 1978, *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building*, John Wiley & Sons, New York, pp. 87-88.

[6]*Op. cit.*, *Applied Linear Statistical Models*, pp. 71-74.

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RESIDUAL STREAM ESTIMATES

The estimated total quantity of residuals for the U.S. petroleum refining industry was subdivided into individual residual streams and management techniques based on the proportion of each in the respondents' total. This method of proportioning the total to the individual categories assumes that the regression equation developed for the total is also valid for each residual stream and management technique. This assumption is not known to be valid, but the procedure is used for consistency with previous surveys. It was deemed, however, that the unknown validity of this assumption renders error or precision estimates of the individual streams meaningless, and therefore stream variances were not calculated for the 1995 survey.

The proportioning procedure begins with the calculation of the ratio of the quantity reported by respondents for a given category to the total quantity reported by respondents. This ratio is then multiplied by the total quantity estimated for nonrespondents. The sum of the quantity reported by respondents plus that determined by proportion for nonrespondents is then the estimated nationwide total for that category.

This procedure may be illustrated by considering the API Separator Sludge stream. This stream represents 20,756 tons of the 1,708,451 total tons reported by respondents, or 1.215%. Applying the 1.215% proportion to the estimated nonrespondent total of 1,340,324 yields 16,285 tons. Adding the respondent and nonrespondent quantities yields an estimated nationwide total quantity of API Separator Sludge of 37,039 wet tons.

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Appendix C
DATA TABLES

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Table C.1—Summary of Respondent Data in Wet Tons: 1995

Management Technique	API Sep. Sludge	Biomass	Contaminated Soils & Solids	DAF Float	FCC Catalyst	Hydro. Catalyst	Other Spent Catalyst	Pond Sediments	Primary Sludges	Slop Oil Emulsion Solids	Spent Cresylic Caustic	Spent Naphthenic Caustic	Spent Sulfidic Caustic	Tank Bottoms	Subtotals
Coker	9,141	37,521	0	49,610	0	0	0	26	43,426	111,448	0	0	0	12,315	263,487
Crude Unit	0	0	0	2,766	0	0	0	0	0	7,043	0	0	176	0	9,985
Cat Cracker	0	26,000	0	20,000	1,287	0	0	0	0	0	0	0	1,969	1,800	51,056
Reclamation	172	0	190	0	242	26,097	805	0	83	0	69,247	77,971	51,478	0	226,284
Regeneration	0	0	0	0	0	1,790	156	0	0	0	6,668	0	248,264	0	256,877
Kiln Feedstock	0	0	921	0	31,139	55	19	0	0	0	0	0	0	0	32,134
Kiln Fuel	3,590	0	128	4,442	0	0	0	1,427	9,055	5,931	0	0	0	1,842	26,416
Recycle Other	0	0	4,693	0	6,493	0	1,133	0	0	0	3,461	0	31,668	0	47,449
Recycle Subtotal	12,903	63,521	5,932	76,819	39,161	27,941	2,114	1,453	52,564	124,422	79,376	77,971	333,555	15,957	913,687
Chemical	0	0	587	0	0	148	0	0	0	0	0	0	823	0	1,558
Heat	2,637	99	15,723	410	0	237	0	0	2,094	1,245	0	0	0	332	22,776
Physical	238	996	0	1,447	0	0	0	0	1,974	0	0	0	0	0	4,655
Wastewater	0	0	0	0	0	0	0	0	0	0	4,880	3,427	46,374	0	54,682
Incineration	2,731	28,564	899	10,376	0	75	78	152	4,872	78	0	0	0	462	48,287
Land Treatment	314	80,974	72,040	0	11,306	0	280	3,818	8,736	27	0	0	0	5,535	183,030
Stabilization	0	1,050	0	0	0	0	0	0	0	0	0	0	0	365	1,415
Treatment Other *	156	60,000	2,058	458	0	0	0	0	0	131	0	0	0	0	62,803
Treatment Subtotal	6,075	171,683	91,307	12,691	11,306	460	358	3,970	17,675	1,481	4,880	3,427	47,197	6,693	379,205
Impoundment	0	200	1,227	0	4,942	0	0	6,250	32	0	0	0	0	0	12,651
Landfill	1,740	90,532	195,628	493	41,453	6,939	6,170	24,752	1,522	12	1,428	0	0	23,577	394,247
DeepWell Injection	0	0	0	0	0	0	0	0	0	0	150	0	5,495	329	5,974
Disposal Other	37	0	0	1,667	0	0	0	0	29	411	0	0	364	180	2,688
Disposal Subtotal	1,777	90,732	196,855	2,160	46,395	6,939	6,170	31,002	1,583	423	1,578	0	5,859	24,086	415,560
Stream Totals	20,756	325,936	294,093	91,669	96,862	35,340	8,642	36,425	71,822	126,327	85,833	81,398	386,611	46,736	1,708,451

* This year's survey had added a separate category for Sludge Digestion. In that there was only one response in this category (the 60,000 tons of Biomass), it has been grouped with Treatment-Other in this summary.

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Table C.2—Nationwide Estimates in Wet Tons: 1995
(1994 amounts shown for comparison have been adjusted to account for residual quantities only, and not recovered oil and water.)

Management Technique	API Sep. Sludge	Biomass	Contaminated Soils & Solids	DAF Float	FCC Catalyst	Hydro. Catalyst	Other Spent Catalyst	Pond Sediments	Primary Sludges	Slop Oil Emulsion Solids	Spent Cresylic Caustic	Spent Naphthenic Caustic	Spent Sulfidic Caustic	Tank Bottoms	1995 Subtotals	1994 Adjusted Subtotals	Percent Change
Coker	16,312	66,957	0	88,531	0	0	0	47	77,495	198,881	0	0	0	21,976	470,199	422,683	11%
Crude Unit	0	0	0	4,936	0	0	0	0	0	12,568	0	0	314	0	17,818	130,544	-86%
Cat Cracker	0	46,398	0	35,691	2,297	0	0	0	0	0	0	0	3,514	3,212	91,111	93,689	-3%
Reclamation	307	0	339	0	432	46,570	1,437	0	147	0	123,572	139,140	91,864	0	403,809	280,230	44%
Regeneration	0	0	0	0	0	3,194	279	0	0	0	11,899	0	443,033	0	458,404	131,490	249%
Kiln Feedstock	0	0	1,644	0	55,568	98	34	0	0	0	0	0	0	0	57,343	54,671	5%
Kiln Fuel	6,407	0	228	7,927	0	0	0	2,547	16,159	10,584	0	0	0	3,287	47,139	47,173	-0%
Recycle Other	0	0	8,375	0	11,587	0	2,022	0	0	0	6,176	0	56,513	0	84,673	469,379	-82%
Recycle Subtotal	23,026	113,355	10,585	137,085	69,884	49,862	3,772	2,593	93,801	222,034	141,648	139,140	595,237	28,475	1,630,498	1,629,859	0%
Chemical	0	0	1,048	0	0	264	0	0	0	0	0	0	1,469	0	2,781	1,993	40%
Heat	4,705	177	28,058	732	0	422	0	0	3,736	2,222	0	0	0	592	40,644	23,466	73%
Physical	425	1,777	0	2,582	0	0	0	0	3,523	0	0	0	0	0	8,308	5,985	39%
Wastewater	0	0	0	0	0	0	0	0	0	0	8,708	6,116	82,756	0	97,581	798,769	-88%
Incineration	4,874	50,973	1,604	18,515	0	134	140	271	8,694	139	0	0	0	825	86,169	87,790	-2%
Land Treatment *	560	144,500	128,558	0	20,176	0	500	6,813	15,589	48	0	0	0	9,877	326,621	586,176	-44%
Stabilization	0	1,874	0	0	0	0	0	0	0	0	0	0	0	650	2,524	559	352%
Treatment Other	278	107,072	3,673	817	0	0	0	0	0	234	0	0	0	0	112,073	29,468	280%
Treatment Subtotal	10,842	306,372	162,940	22,647	20,176	821	640	7,085	31,542	2,643	8,708	6,116	84,225	11,944	676,701	1,534,206	-56%
Impoundment	0	357	2,190	0	8,819	0	0	11,153	57	0	0	0	0	0	22,576	26,409	-15%
Landfill	3,105	161,557	349,103	879	73,974	12,383	11,010	44,171	2,716	22	2,548	0	0	42,075	703,544	999,484	-30%
DeepWell Injection	0	0	0	0	0	0	0	0	0	0	267	0	9,807	587	10,661	27,291	-61%
Disposal Other	66	0	0	2,975	0	0	0	0	51	733	0	0	650	321	4,797	14,993	-68%
Disposal Subtotal	3,171	161,914	351,292	3,855	82,793	12,383	11,010	55,324	2,825	756	2,816	0	10,456	42,983	741,578	1,068,177	-31%
1995 Stream Totals	37,039	581,642	524,817	163,587	172,853	63,066	15,421	65,002	128,169	225,433	153,172	145,257	689,918	83,402	3,048,776	4,232,242	-28%
1994 Stream Totals	101,395	772,826	661,124	355,176	286,152	53,306	18,086	142,854	327,568	48,815	156,802	219,736	1,001,630	86,772	4,232,242		
Difference	64,356	191,184	136,307	191,589	113,299	(9,760)	2,665	77,852	199,399	(176,618)	3,630	74,479	311,712	3,370	1,183,466		
Percent Change	-63%	-25%	-21%	-54%	-40%	18%	-15%	-54%	-61%	362%	-2%	-34%	-31%	-4%	-28%		

* Land Treatment combines the previous Land Treatment and Disposal-Landspread categories. The quantity shown for 1994 is the sum of these two categories.

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Table C.3—Number of Respondents for Each Category: 1995

Management Technique	API Sep. Sludge	Biomass	Contaminated Soils & Solids	DAF Float	FCC Catalyst	Hydro. Catalyst	Other Spent Catalyst	Pond Sediments	Primary Sludges	Slop Oil Emulsion Solids	Spent Cresylic Caustic	Spent Naphthenic Caustic	Spent Sulfidic Caustic	Tank Bottoms
Coker	6	3	0	9	0	0	0	1	8	7	0	0	0	5
Crude Unit	0	0	0	2	0	0	0	0	0	2	0	0	2	0
Cat Cracker	0	1	0	1	4	0	0	0	0	0	0	0	1	1
Reclamation	1	0	1	0	1	43	19	0	3	0	19	5	15	0
Regeneration	0	0	0	0	0	15	7	0	0	0	2	0	6	0
Kiln Feedstock	0	0	1	0	24	1	1	0	0	0	0	0	0	0
Kiln Fuel	19	0	3	9	0	0	0	1	19	12	0	0	0	14
Recycle Other	0	0	2	0	6	0	2	0	0	0	5	0	20	0
Recycle Subtotal	26	4	7	21	35	59	29	2	30	21	26	5	44	20
Chemical	0	0	1	0	0	1	0	0	0	0	0	0	1	0
Heat	6	1	10	2	0	2	0	0	10	3	0	0	0	3
Physical	1	1	0	2	0	0	0	0	2	1	0	0	0	0
Wastewater	0	0	0	0	0	0	0	0	0	0	4	5	18	0
Incineration	16	3	9	6	0	3	1	1	32	6	0	0	0	17
Land Treatment	2	17	15	0	3	0	4	1	2	1	0	0	0	10
Stabilization	0	1	0	0	0	0	1	0	0	0	0	0	0	2
Treatment Other	1	1	1	1	0	0	0	0	0	1	0	0	0	0
Treatment Subtotal	26	24	36	11	3	6	6	2	46	12	4	5	19	32
Impoundment	0	1	1	0	1	0	0	1	1	0	0	0	0	0
Landfill	9	26	52	2	35	17	30	7	14	1	1	0	0	39
DeepWell Injection	0	0	0	0	0	0	0	0	0	0	2	0	6	1
Disposal Other	1	0	0	1	0	0	0	0	1	1	0	0	1	1
Disposal Subtotal	10	27	53	3	36	17	30	8	16	2	3	0	7	41
Stream Totals *	50	46	67	28	52	55	45	12	61	28	30	10	56	58

* The subtotals exceed the stream totals because some facilities report more than one management technique for a stream.

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