Journal of Hazardous Materials, 23 (1990) 293-315
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

HAZARDOUS WASTE GENERATION, TRANSPORTATION, RECLAMATION, AND DISPOSAL: CALIFORNIA'S MANIFEST SYSTEM AND THE CASE OF HALOGENATED SOLVENTS*

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Summary

This paper is an analysis of data collected by the California Department of Health Services (DHS) on the transportation of halogenated solvent wastes for the time period 1984 through 1988. Major changes in public policies that have affected generation and disposal patterns are described and evidence in the data of their effectiveness is evaluated. A materials balance model is developed for the purpose of estimating hazardous waste generation, reclamation, and disposal for the major cleaning applications of halogenated solvents. The results are of interest to government and industry officials in California, other states, and other countries who are basing policies on measurements of hazardous waste generation, transportation, reclamation and disposal.

Introduction

Among all developments in hazardous waste regulation, the restrictions on land disposal have had the most profound and widespread impacts on waste management practices. California's program to move away from land disposal was authorized in 1981 and was the first in the nation. The 1984 Amendments to the Resource Conservation and Recovery Act (RCRA) authorized the federal program for land disposal restrictions. The primary purpose of this analysis is to examine available data and to look for evidence of how these and other regulations have influenced waste disposal practices.

In what follows, the major halogenated solvents, as well as State and federal programs designed to reduce generation and land disposal are introduced. Then, we describe data from the State hazardous waste manifest system, and analyze trends in off-site transportation and disposal of halogenated solvents for a five year period during which the land disposal restrictions were implemented. Finally, a materials balance model is described that can be used to develop estimates of generation, reclamation, and disposal of halogenated solvents.

*Views expressed in this paper are the author's own and are not necessarily shared by RAND or its research sponsors.

0304-3894/90/$03.50

Halogenated solvents and their applications

There are five major halogenated solvents that are used in a very diverse assortment of production applications in California. These include trichloroethylene (TCE), methylene chloride (METH), perchloroethylene (PERC), 1,1,1-trichloroethane (TCA), and chlorofluorocarbon 113 (CFC-113). The vast majority of TCE is used for cleaning fabricated metal parts in industries such as aerospace, electronics, and automobiles, however, it is also used as a chemical intermediate and for miscellaneous solvent applications including fabric scouring, fumigants, adhesives, and paints. The major uses of METH are paint removal, aerosols, and chemical processing. More than half of PERC use is for dry cleaning, and other uses include chemical intermediates and metal cleaning. TCA use is dominated by commercial metal cleaning operations, and it is used to a lesser extent for aerosol applications, adhesives, paints and coatings, and electronics. CFC-113 use is predominantly for cleaning applications in industries such as electronics, but it is also used to a much smaller extent for dry cleaning and plastic foam manufacture [1].

The health and environmental effects of halogenated solvents are as diverse as their applications. PERC has been shown to increase the incidence of cancer in rats. PERC and TCE are potentially toxic air pollutants that may form precursors that lead to photochemical smog. TCA and CFC-113 contribute to potential ozone layer depletion in the stratosphere [2,3].

The regulatory response to these hazards has been not only to restrict land disposal, but also to restrict air emissions and water releases. CFC-113 has recently been regulated with a production cap, and TCA is under consideration for similar regulation.

California's hazardous waste manifest system

California was one of the first states in the United States of America to implement a system to track the transportation of hazardous wastes from their generation to their final disposal. The purpose of such a system is to monitor shipments so that illegal dumping is deterred. The system is also designed to provide information on hazardous waste streams such as quantities, types of wastes, and methods of disposal. When Congress later authorized the federal tracking system, it was their intent that the manifest system play a central role in the overall plan to assure proper management of hazardous wastes. The federal manifest system was designed to create clear lines of accountability, to provide transporters and emergency personnel with waste constituent information so they can protect health and the environment, and to provide a means of recordkeeping and reporting [4].

Before RCRA, the State had developed its own manifest form. The 1976 RCRA legislation required that certain information be included on state manifest forms, but it did not require the use of a federal form [4,5]. In a joint rulemaking procedure in 1984, the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Transportation (DOT) required the use of one manifest form, the Uniform Hazardous Waste Manifest, because different manifest forms in different states had caused confusion and compliance difficulties for interstate shipments [6]. This form has space allocated for information that states require for their particular manifest programs. Below is a description of the regulations governing the manifest system in California for hazardous waste generators, transporters, and facilities.

Generator requirements

Before the generator can send hazardous wastes for transportation off site, the manifest form must be filled out including information about the generator, transporter, facility, and type and quantity of waste [7]. An EPA identification number must be specified for each generator, transporter, and facility. Federal regulations require waste type specification by the DOT hazard classification numbers (combustible liquid, corrosive material, etc.). The State requires waste types to be recorded with a three digit waste code which provides more detailed information on waste composition. When a transporter receives wastes from the generator, the generator is then required to send a copy of the manifest form to the Department of Health Services (DHS). If the generator does not get a copy of the manifest back from the disposal facility within 30 days, the generator is required to contact the disposal facility; if the manifest is still not received after 45 days, the generator must notify the DHS of their efforts to contact the facility. Generators are required to submit summary information on the hazardous wastes that they generate every two years – the so called biennial report – for waste disposal on site and off site.

Transporter requirements

Only registered transporters are permitted to transport hazardous wastes in the State [8]. The transporter requirements apply to all transporters who ship manifested wastes into, out of, through, or within the State for all off-site shipments. Transporters cannot accept wastes for shipment without a manifest form that has been completed and signed by the generator. The transporter fills out and signs the transporter section of the form before leaving the generator. The transporter must keep the manifest with the waste for the entire journey and give a copy to the facility upon arrival. For wastes shipped out of state, the transporters must send a completed and signed manifest back to the DHS within fifteen days of arrival at the facility.

Facility requirements

The receiving facility must sign the manifest, note any discrepancies, and then give one copy to the transporter, send one copy to the generator, and send one copy to the DHS within 30 days [9]. The facility has the responsibility for filling in the code for handling method on the manifest form. Each year the facility submits to the State an annual report including information on quantity and type of manifested wastes received, generators who sent it, and how it was handled or disposed. Federal regulations require a biennial report from facilities. On-site disposal facilities report once a month on each of the waste types, quantities, and disposal methods.

The data defined exactly

From the description of the California hazardous waste manifest system, we can understand what data are included in the manifest data base. First of all, the data are only those wastes that were transported off site. On-site recycling or treatment is not included, however, if residuals from these processes are shipped off site they would require a manifest.[1] Hazardous waste shipments from small quantity generators and small shipments from any generator are all included – regardless of how small the generator or how small the shipment. Wastes that are shipped to California from out of state are tracked with a California manifest, and hence would be included in the manifest data base. Wastes that are generated in California, but are shipped out of state use the receiving state's manifest form if that state has one, and the California form otherwise. One staff officer from the DHS made a general estimate that about 70% of shipments out of state are included in the California manifest data base. For the case of halogenated solvents, we found only one reclaimer who shipped substantial amounts of waste out of state, and these wastes were included in the manifest data base because they were manifested on their way from generators to a transfer station before leaving the state.

Waste codes 211 and 251

Waste codes 211 and 251 are the categories that capture the majority of the halogenated organic compounds. Codes 211 and 251 are wastes from solvent applications of halogenated organic compounds, and it is these applications that we focus on in this analysis. Solvent applications are those where the solvent is used to dissolve or remove certain constituents.[2] As mentioned previously, the five major halogenated solvents comprise the majority of halogenated solvent use. Hence, the 211 and 251 categories are composed primarily of TCE, PERC, METH, TCA, and CFC-113. Other waste categories that contain

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[1]Since there is now virtually no on-site disposal of halogenated solvent wastes in California, the manifest data no longer omit such wastes.

[2]cf., nonsolvent applications include foam blowing, aerosols, chemical production, etc.

halogenated organic compounds are smaller waste streams and/or from specific non-solvent applications.[3]

The 211 waste code (halogenated solvents: chloroform, methylchloride, perchloroethylene, etc.)[4] represents the bulk of liquid halogenated organic wastes. These wastes are the spent halogenated solvents or residuals from partial on-site reclamation of spent halogenated solvents when they are shipped off site for reclamation. For example, the vast majority of dry cleaning wastes transported to reclamation are listed as 211 wastes, including filter muck, cartridges, and residual sludge from distillation. This category corresponds roughly to the spent solvents in federal waste categories F001 and F002 [10].

Waste code 251 wastes (still bottoms with halogenated organics) are the halogenated solvent waste residuals that result from reclamation on-site when those residuals are transported for disposal or further reclamation. An example is a large aerospace manufacturing plant with its own capacity for extensive reclamation which would generate still bottom wastes. Waste code 251 roughly corresponds to the still bottoms in federal waste categories F001 and F002 [10,11].

Problems with the data

There have been several problems that the Department of Health Service has faced in operating and maintaining the hazardous waste manifest system. Perhaps the greatest difficulty has been handling the large number of manifests; two copies each from 300,000 manifest forms are received each year, for a total of 600,000 pages. The problem was summarized in a 1984 observation [12]:

> "The State has been bombarded by and has encouraged a blizzard of manifests, boxes and boxes and rooms full of manifests. Trying to get that data into a computer in a way that it can be analyzed and managed meaningfully has been a very difficult task. It's been a joke up to now, frankly."

The system has improved substantially in recent years, and now all of the manifests are entered into the central data base and can be compiled into summary sheets with specific cross sections of information. The remaining problems concern errors, matching manifests, and the lack of definitions of waste codes.

One staff member recounted an instance where he noticed an usually high waste tonnage only to discover later by phone confirmation that the units re-

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[3]For example waste code 214 (unspecified solvent mixture) contains halogens from solvent applications, but in small concentrations. The supplementary Appendix (available from the author) includes a description of other waste codes that contain halogenated organic compounds. The waste code definitions in this paper are generalizations of how the waste codes are used by generators, and are based on interviews with industry sources.

[4]California Department of Health Services (1989). It is not clear why methylchloride and chloroform are listed as examples of 211 wastes. Chloroform is used only in very small quantities in solvent applications. Methylchloride is a gas used in nonsolvent applications.

ported were in pounds rather than in tons. When such errors are known, the manifests are placed in the "suspense file" to distinguish them from manifests without known errors in the "history file". In 1986, the DHS reported that 30% of the manifests received had errors, down from 40% in 1983 [13,14]. One reclaimer who has examined the data found 50 different variations for the EPA Identification number of one disposal facility, and estimated that about 50% of the manifests have errors when considering all errors, including DOT shipping names. Errors on the manifests are largely incorrect EPA identification numbers, waste descriptions and shipping names, quantities, or waste codes. A smaller number of data entry errors are added when the information is loaded into the computer data base. A limited budget has prohibited substantial follow up of manifest errors.[5]

Manifest errors have made it difficult to match the generator's copy of the manifest with that of the facility, and hence the system has not been able to confirm the proper transportation of hazardous wastes. The system could match only one half of the manifests in 1983, but by 1986 DHS reported that it could match 95% of manifests [13–15] (due in large part to the addition of preprinted manifest form numbers). One staff officer now estimates that about 85% of the manifests are matched by form number, EPA number, and waste stream. Despite improvements, the Department is still not using the system to track suspected illegal shipments because the number of unmatched manifests is considered being too large.

The choice of waste code is left up to the generator of the hazardous waste. The only definitions of waste codes that are available for the generators are the short waste code names that are found on the back of the manifest form. (e.g., 211 halogenated solvents: chloroform, methylchloride, perchloroethylene, etc.). This leaves room for error and overlapping definitions that could be avoided with more specific definitions of waste categories. If the definitions are taken at face value, then all of waste categories with halogenated organic constituents (211, 251, 341, and 351) could also fit into the waste categories 741 and 751.[6]

When separate waste codes are listed on separate lines they are tracked separately, however, when there is more than one waste code on a line, then the first of these codes is entered into the data base. There are often mixtures of wastes that could fit into more than one waste code and we have no way of knowing wether the generator listed the highest concentration waste first, or even wether lesser concentration wastes are listed at all. Facilities must also

[5]Senate Bill 457, 1989, includes a provision for a $20 cost recovery for manifest errors. This could be per manifest or per error.

[6]The supplementary Appendix includes a description of waste codes that contain halogenated organic compounds. Implicit in these waste definitions is a hierarchy of waste codes, however, there is confusion among generators and reclaimers as to which direction the hierarchy should proceed.

make selections among multiple waste codes when they are preparing the annual facility report that is submitted to the DHS. Without information on the proportion of each of the waste types in each entry, this assignment to waste code is largely arbitrary.

Halogenated solvent wastes could be blended in other waste codes such as 212 (oxygenated solvents) or 213 (hydrocarbon solvents) if they appear in smaller proportions. The sum total of the halogenated solvents in waste codes that are not specifically designated halogenated wastes may be significant and cannot be determined from the waste code. Even if other solvents are mentioned in the additional description on the manifest form, they are not entered in the manifest data base.

Some, but not all of the waste handling methods are defined in the California Code of Regulations.[7] There is still ambiguity about some of these definitions and their use has changed significantly over the years. For example, the handling of solvent waste streams at a cement kiln was classified in the "other" handling code and sometimes "thermal treatment" until 1986, and has since been classified as "recycling". From the manifest data alone there is no way to distinguish between solvent reclamation and solvent reuse as a supplementary fuel.

Major policy changes affecting disposal of hazardous wastes

California's land disposal restrictions

In many ways, the 1981 report of the Office of Appropriate Technology (OAT) was the seminal work on alternatives to land disposal which spawned both the California and federal land disposal restrictions [16]. The report characterized all of the major hazardous waste streams and alternatives to land disposal were identified. Soon after the OAT released their findings, the Governor issued Executive Order B-8881 which tasked the Department of Health Services with prohibiting land disposal of certain hazardous wastes, setting higher fees for land disposal, increasing monitoring and enforcement, and encouraging the private sector to build treatment facilities.

The Department of Health Services promulgated regulations in 1982 on the land disposal of certain "restricted" hazardous wastes according to a series of deadlines. Free liquid wastes containing halogenated organic compounds in concentrations greater than 1000 mg/kg were prohibited from land disposal as of January 1, 1985. Organic sludges and solids containing halogenated organic compounds in concentrations greater than 1000 mg/kg were proposed to be restricted from land disposal after July 1, 1985. Restricted wastes could be land disposed before the deadline if they were in small containers and lab packs

[7] Handling methods are described in supplementary Appendix C (available from the author).

within steel shipping containers [17]. Small quantity generators were not exempted from land disposal restrictions.

The restrictions took effect only if the Department determined that there was adequate technology and capacity for alternatives to land disposal. As such, the deadline for solids and sludges with concentrations of halogenated organic compounds ≥1000 mg/kg was postponed several times and now is listed as July 8, 1992.[8] The regulations also included provisions for variances for particular waste streams and site specific methods of disposal, as well as provisions for emergency variances in cases of spilled wastes where there is no recycling or treatment technology available [18].

Although the California land disposal restrictions were the first of their kind, they were seen to be inadequate by 1984. The limitations of the original land disposal restrictions included a "treatment loophole", which specified that surface impoundments may not be considered land disposal if they are dredged within 12 months of hazardous waste discharge. As a result, the Toxic Pits Cleanup Act of 1984 was enacted to further restrict discharge of hazardous wastes into unlined surface impoundments after July 1, 1985. Although this legislation closed the treatment loophole for surface impoundments, it did not for other forms of land disposal [19,20] Table 1 lists the various State and Federal Policy changes as adopted in the period 1984–1988.

RCRA and HSWA land disposal restrictions

The Hazardous and Solid Waste Amendments (HSWA) to RCRA were enacted on November 8, 1984 for the purpose of minimizing the land disposal of

TABLE 1

Policies affecting land disposal of halogenated solvent wastes (1984-88)

Policy change	Effective date	Reference
California Land Disposal Restrictions:		
Free liquid wastes ≥1000 mg/kg	January 1, 1985	[21]
Treatment loophole closed	July 1, 1985	[22]
Solids and sludges ≥1000 mg/kg	July 8, 1992	[21]
RCRA Land Disposal Restrictions:		
Bulk and noncontainerized liquids	May 8, 1985	[23]
Containerized wastes	February 8, 1986	[23]
Treatment residuals ≥0.05–1.05 mg/l	November 8, 1986	[24]
Wastes with delayed deadline	August 8, 1988	[24]

[8]DHS has delayed the state land disposal restrictions for solids and sludges because of inadequate capacity.

hazardous wastes. Much of this federal program was modelled after California's land disposal restrictions. On May 8, 1985, bulk or non-containerized liquid hazardous wastes were prohibited from land disposal regardless of liners, leachate collection systems, or absorbents. By November 1985, the disposal of any nonhazardous liquids in hazardous waste landfills was prohibited. By February 8, 1986, EPA was required to minimize the land disposal of containerized hazardous wastes and to minimize the free liquids in containerized hazardous wastes. Absorbent materials that biodegrade or release liquids when compressed were not acceptable methods [24].

The core of the HSWA legislation included statutory deadlines for promulgation of treatment standards, and halogenated solvent wastes were among those affected by the first such deadline. If treatment standards had not been promulgated by the deadline, the so called "hammer" provisions would have required the automatic prohibition of these wastes from land disposal. The treatment standards were designed to allow land disposal only for residuals with concentrations less than or equal to that of the 'best demonstrated available treatment' technologies (BDAT) to diminish toxicity and reduce migration. In this way, HSWA's intent to eliminate or minimize land disposal was fulfilled. The deadline for halogenated solvent wastes was November 8, 1986, and on November 7, 1986, EPA's final rule was published [23].

The final rule also specifies several wastes that contain halogenated solvents but are scheduled for a delayed deadline of November 8, 1988. These include: 1) wastes from small quantity generators defined as those generating between 100 and 1000 kg of hazardous waste per month, 2) wastes disposed of in injection wells, 3) wastes from CERCLA response actions of RCRA corrective actions, and 4) other solvent–water mixtures, solvent-containing sludges, and solvent-contaminated soil with less than 1% (by weight) solvent constituents. After the delayed deadline, these wastes were subject to the same restrictions as described above [25].

Several variances to the HSWA land disposal restrictions are also allowed in the final rule. A statutory exemption is available for treatment of wastes in surface impoundments if the facility meets certain technical requirements and if the residues that do not meet the treatment standards are removed after one year at the latest. Another variance is described for wastes that have unique properties such that they cannot be treated with the specified BDAT and other treatment capacity or technology does not exist. Finally, a variance can be granted if it can be demonstrated that there will be no migration of the wastes for as long as it remains hazardous [26,27].

Other factors affecting hazardous waste management and disposal

State programs for recycling and waste minimization

The Department of Health Services first promulgated regulations to promote recycling in 1979 [28]. The State maintains a list of hazardous wastes that can be recycled, and waste codes 211 and 251 are included. Generators of recyclable wastes must recycle them or provide written justification for not doing so if DHS requests. In 1985, the title "resource recovery" facilities was designated for hazardous waste facilities that recycle to reduce the stigma of such facilities and promote siting. The State maintains a waste exchange program that publishes a directory of commercial recyclers and a newsletter/catalog which lists wastes available and wastes wanted. Until 1986, DHS reviewed manifest forms with the aim of contacting and informing generators of the potential to recycle wastes that were disposed of by other means [29].

The State activities for waste minimization include a financial loan program for pollution control, a grant program for research and development, as well as a technical assistance and information transfer program with regulatory fact sheets and seminars. Waste audits were conducted for the automotive paint shop, paint manufacturing, automotive repair, and printed circuit board manufacturing industries. The manifest form now includes a certification that generators have programs to reduce the volume and toxicity of hazardous waste they generate [30].

Cost and capacity of reclamation and disposal

The cost of land disposal rose sharply in the years before the land disposal restrictions as new controls were required and capacity diminished. Between 1983 and 1986, the cost for land disposal of a particular waste increased 450 percent from $41 per ton to $185 per ton including disposal, transportation, and taxes [31]. For extremely hazardous wastes, the combined California land disposal tax and fee was $59.34 in 1984 and $102.44 in 1987. These taxes and fees are used to support the State's hazardous waste regulatory and cleanup programs, as well as to provide incentives to reduce the land disposal of hazardous wastes.

Since the land disposal restrictions, the cost effective management method for halogenated solvent wastes has been to reclaim spent solvent and dispose of the residuals of the reclamation process as a supplemental fuel in a cement kiln. Reclamation can be either on site or off site. In California, commercial off-site reclaimers will credit generators for spent halogenated solvent wastes with adequate solvent concentrations (this is not true for most of the U.S.). Destructive incineration, cement kiln, and land disposal (only of BDAT equivalent residuals) are the only legal means of disposal of halogenated solvent residuals. Since there are no incinerators with this function in California, and extensive treatment is prohibitively expensive for these wastes, most of the residuals of the reclamation process are used as a fuel supplement in a cement kiln. Some halogenated solvent wastes are sent out of state for reclamation, and a smaller amount of sludge is transported out of state for destructive incineration. Although the capacity for land disposal has dwindled rapidly, there is no shortage of capacity for reclamation and residuals disposal as it is now practiced for the major halogenated solvent cleaning applications.

Although there is no facility to incinerate solids with halogenated solvents (filters, diatomaceous earth, sludge still bottoms, etc.) in California, the cement kiln plans on adding this capacity next year. Until that time, reclaimers face the choice of either limiting the level of reclamation so that the residual still bottom is not so solid that it cannot be blended into the liquid fuel supplement, or using reliquification equipment that will allow more extensive reclamation. At the same time, the chlorine content of the fuel blend mixture cannot exceed specifications. The net effect is a balance of reclamation and blending with other flammable liquids. Hence, the capacity for cost effective incineration of solids at the cement kiln could have the effect of increasing the level of reclamation beyond its existing level by allowing the maximum possible reclamation without the need for reliquification of still bottom sludges.

State and federal Superfund programs

Under State and federal Superfund programs, firms can be sued to recover cleanup costs as well as property damage and personal injury that result from hazardous waste disposal. In some cases, the firm with the greatest ability to pay may be assessed the cost of cleanup and then have the task of recovering costs from the other responsible parties. Superfund legislation has provided a large incentive for the reduction of hazardous wastes at their point of generation so that long term liability is reduced. Additionally, insurance has become more expensive and difficult to acquire.

Trends in manifest data

The following is a description of trends in the manifest data (cf. Tables 2 and 3 for code 211 waste trends and Tables 4 and 5 for code 251 waste trends) and a brief explanation of why these patterns make sense in light of the State and Federal policy changes of 1984–1988 described above. The explanations are educated guesses and somewhat speculative.

211 Waste code trends

Injection well disposal was last listed in 1984, and has been zero since. The end of injection well disposal is due to the closure of the Rio Bravo well, which was the only injection well used for this purpose in California.

Landfill disposal decreased slightly in 1985, doubled in 1986, and was followed by large decreases in 1987 and 1988. In 1986, landfill methods reached their high point at 12% of total code 211 disposal. At first glance, the decrease in 1985 is surprisingly small considering this was the first full year of the California free liquids restrictions. However, the interpretation of the free liquids restrictions was that landfilling was permitted if the liquids were solidified with material such as kitty litter, sawdust, or floorsweep. This solidification did not make the wastes fit the 251 waste code (still bottoms), so waste code 211 was still used. After May of 1985, federal regulations restricted bulk and noncontainerized wastes, but the same wastes could still be landfilled in containers. On February 8, 1986, federal regulations restricted the use of biode-

TABLE 2

Waste code 211 manifest data (tons)

Handling method	1984	1985	1986	1987	1988[a]
Injection well	156	0	0	0	0
Landfill	988	932	1974	556	194
Land application	67	0	1	0	0
Surface impoundment	456	3215	715	116	0
Other	940	1388	1418	576	251
Recycle	11029	9689	10468	9389	9673
Tank treatment	0	80	188	222	158
Treatment pond	0	141	0	5	0
Thermal treatment	25	29	1476	516	128
Neutralization	122	67	0	1	0
Filtration	0	21	0	0	0
Stabilization pond	0	0	0	2	0
Unknown	791	3420	2315	2260	1888
Total	14574	18982	18555	13643	12292

[a]Draft 1988 data.

TABLE 3

Waste code 211: proportion of total without unknown

Handling method	1984	1985	1986	1987	1988
Injection well	0.01	0.00	0.00	0.00	0.00
Landfill	0.07	0.06	0.12	0.05	0.02
Land application	0.00	0.00	0.00	0.00	0.00
Surface impoundment	0.03	0.21	0.04	0.01	0.00
Other	0.07	0.09	0.09	0.05	0.02
Recycle	0.80	0.62	0.64	0.82	0.93
Tank treatment	0.00	0.01	0.01	0.02	0.02
Treatment pond	0.00	0.01	0.00	0.00	0.00
Thermal treatment	0.00	0.00	0.09	0.05	0.01
Neutralization	0.01	0.00	0.00	0.00	0.00
Filtration	0.00	0.00	0.00	0.00	0.00
Stabilization pond	0.00	0.00	0.00	0.00	0.00
Total	1.00	1.00	1.00	1.00	1.00
(Unknown)[a]	(0.05)	(0.18)	(0.12)	(0.17)	(0.15)

[a]Proportions computed with unknown.

gradable absorbents, but solvent wastes could still be landfilled if they were containerized with nonbiodegradable absorbents. So even though the California free liquid restrictions took effect January 1, 1985, code 211 liquid wastes that had been solidified could be land disposed until the November 1986 federal restrictions. Landfill disposal dropped in 1987 – the first full year with the federal land disposal restrictions – by 72%.

It is interesting to note that the large increase in 1986 is concurrent with the large decrease in surface impoundment. One possible explanation is that the Toxic Pits Cleanup Act of 1984 had the effect of shifting disposal patterns away from surface impoundments to landfills.

It is unclear why there are still 211 wastes transported to landfill in 1987 and 1988. Four possible explanations are: 1) these are non-RCRA wastes that require incineration, and therefore would be legal for land disposal under Californian regulations, 2) these wastes could be non-RCRA wastes that have been shipped out of state to states that do not have their own manifest form, 3) they could be an unusual halogenated solvent that is not on the California list, or 4) these entries could simply be errors, such as listing halogenated organic material that is not specifically a solvent.

Land application was less than one percent in 1984 and has been zero otherwise, except in 1986 when one ton was reported.

Surface impoundment disposal radically increased by over 600% in 1985, while 1986 through 1988 shows rapid decline to zero. About 1985, the disposal sites started to look more carefully at the wastes they were receiving. Perhaps some of the "mud and water" loads were found to have low levels of halogenated solvent material, and perhaps they were then surface impounded as code 211 waste for lack of a better waste code for such aqueous waste streams. There are other halogenated organic compound waste codes, but none for aqueous waste and none that specify solvents. These aqueous waste streams are large in volume, hence the large increase in 1985 surface impoundment. The Toxic Pits Cleanup Act's closure of the treatment loophole for surface impoundments went into effect in July 1985, and may be evidenced by the drop in surface impoundments in 1986 – presumably the unlined impoundments. After November 1986, federal law still permitted surface impoundment if certain technical criteria were met, which may explain the remaining surface impoundment in 1987. The drop to zero by 1988 reflects the closure of the Casmalia surface impoundment facility.

Other increased steadily until 1986, and has decreased steadily in 1987 and 1988. This category decreased from a high of 9% of 211 waste in 1985 and 1986 to a low of 2% in 1988. Other was the category that was used for most of the wastes that were transported to cement kilns for disposal until 1986. This explains the precipitous drop in this waste handling method in 1987 and 1988. Perhaps the remaining wastes reported as other are out-of-state cement kilns who are still using this handling code. Otherwise, we do not have an explanation of what the other waste handling method really is in 1987 and 1988.

Recycling tonnage in absolute terms has not changed dramatically over the entire 1984–1988 period. However, there has been a steady increase in the proportion of 211 recycled from 62% in 1985 to 93% in 1988. The reason for the drop in 1985 is not immediately apparent, especially since total 211 wastes increased by 30% in this year. It was coincident with a sharp increase in surface impoundment and unknown disposal however, it is unclear why generators would switch to land methods while their waste could be recycled.

Tank treatment first appeared in 1985, and has remained a small component — 1 or 2% of code 211 wastes — ever since.

Treatment pond shipments appeared in 1985 at the small rate of 1 percent of manifested wastes, and a still smaller amount in 1987. Otherwise it has been zero. The 1985 figure may have been due to the treatment loophole that existed until July 1985.

Thermal treatment was small in 1984 and 1985, but increased dramatically in 1986 – from virtually 0% to 9% of code 211 manifested wastes. Since 1986, its use has dropped off significantly to only 1%. This waste handling method was originally called incineration, and was changed to thermal treatment (including incineration) by about 1986. Thermal treatment has been used for cement kiln fuel blending, along with "other" to at least a small extent, which may explain the drop in 1987 when the change to recycling took place. Incineration refers to facilities that are exclusively meant for hazardous waste destruction, and other thermal treatments include heating filter cake to reduce volume, and the liquid injection process. The 1986 increases may have been incineration that replaced surface impoundment disposal of these wastes, although it is not clear why incineration would be chosen over reclamation for most wastes.

Neutralization was used on a small scale in 1984 and 1985, and decreased to zero thereafter. 211 wastes were manifested for *Filtration* only in 1985 for a small amount. *Stabilization Pond* disposal was manifested only for a very small amount of 211 wastes in 1987.

Unknown has remained relatively constant in terms of proportion of total disposal, as we expect as long as there is no systematic cause of these errors. This proportion is not trivial, ranging from 5 to 18% of all code 211 waste disposals. The unknown waste handling method is entered when there is a blank or obvious mistake on the manifest form.

251 Waste code trends

Injection well disposal was 6% of code 251 waste in 1984, but has been zero ever since. Again, the Rio Bravo well closed in 1984.

Landfill of 251 wastes increased steadily from 1984 to 1986 when it was at its height of 38% of 251 wastes manifested. Then a huge drop to almost no landfilling in 1987 and 1988 followed. It seems clear that this precipitous drop off is due to the fact that 1987 was the first full year of the HSWA land disposal restrictions. To the extent that the landfilled sludges were from the dry cleaning industry, the drop is coincident with an increase in route service pickup and shipments out of state of one major reclaimer. Since still-bottom sludges are not free liquids, they were not affected by the California restrictions before this time.

Land application was 9% of total 251 disposal in 1984, but dropped to only 1% in 1985, and to zero thereafter. Aside from land disposal restrictions, land application of halogenated organics is heavily affected by VOC air regulations.

Surface impoundment disposal remained very small in 1984 and 1985, boomed in 1986, then became very small again in 1987 and zero in 1988. Until the November 1986 deadline, 251 wastes could still be disposed in landfills if containerized. After the November deadline, landfilling was not permitted, however, surface impoundments could attain variances until 1988 if the facility met certain technical criteria. Hence the surface impoundment boom of 1986. The end of the boom in 1987 coincides with the closure of the Casmalia surface impoundment, which left the Chemical Waste Management, Inc. facility as the only surface impoundment in California. This facility did not accept halogenated solvent wastes because of potential deterioration of the surface liner.

Other increased sharply in 1985 from 19 to 48% of total 251 disposal and then fell back to 20% of total disposal in 1986. In 1987 and 1988, other disposal for code 251 waste dropped to near zero levels. As mentioned previously, the "other" waste handling method was used for wastes that were bound for cement kiln destruction until 1986. This explains the sharp drop in 1987.

Recycling increased dramatically from 10% in 1986 to 60% in 1987. The in-

TABLE 4

Waste code 251 manifest data (tons)

Handling method	1984	1985	1986	1987	1988[a]
Injection well	130	0	0	0	0
Landfill	461	613	799	7	5
Land application	187	15	0	0	0
Surface impoundment	63	23	676	26	0
Other	403	855	406	1	5
Recycle	401	156	199	735	549
Tank treatment	0	0	0	20	0
Thermal treatment	459	103	0	435	273
Unknown	153	1040	1312	992	396
Total	2257	2805	3392	2216	1228

[a]Draft 1988 data.

TABLE 5

Waste code 251: proportion of total without unknown

Handling method	1984	1985	1986	1987	1988
Injection well	0.06	0.00	0.00	0.00	0.00
Landfill	0.22	0.35	0.38	0.01	0.01
Land application	0.09	0.01	0.00	0.00	0.00
Surface impoundment	0.03	0.01	0.33	0.02	0.00
Other	0.19	0.48	0.20	0.00	0.01
Recycle	0.19	0.09	0.10	0.60	0.66
Tank treatment	0.00	0.00	0.00	0.02	0.00
Thermal treatment	0.22	0.06	0.00	0.36	0.33
Total	1.00	1.00	1.00	1.00	1.00
(Unknown)[a]	(0.07)	(0.37)	(0.39)	(0.45)	(0.32)

[a]Proportions computed with unknown.

crease in 1987 is consistent with the land disposal restrictions, and with the switch from other to recycling for cement kiln fuel blending.

Tank treatment was only 2% in 1987.

Thermal treatment decreased rapidly to a low of zero in 1986, and then increased in 1987. In terms of proportion of code 251 wastes, thermal treatment was low until 1987 and 1988 when it jumped to 36% and 33% of total 251 disposal. This jump is coincident with the land disposal restrictions, and may represent increased incineration of still bottoms.

Unknown manifest reports increased rapidly in 1985 and 1986, but decreased substantially thereafter. In terms of proportion of total 251 disposal, unknown has been high and fairly steady since 1985. 1987 was the high point of 45% of total 251 transportation.

Materials balance estimation of waste generation and recycling

Certainly, the level of *transportation* of hazardous wastes is of interest to policy makers in terms of highway safety and emergency response. Of further importance is the level of hazardous waste *generation, reclamation,* and *disposal.* With the help of a materials balance model, we can distinguish between waste generation, reclamation, and disposal, and then make rough estimates for the case of halogenated solvents.

The materials balance model in concept

Figure 1 schematically represents a materials balance model of halogenated solvents from their production to their final disposition as air emissions or hazardous waste disposal. *Generation of solvent wastes* takes place when the solvents are spent and no longer effective in their production application. The

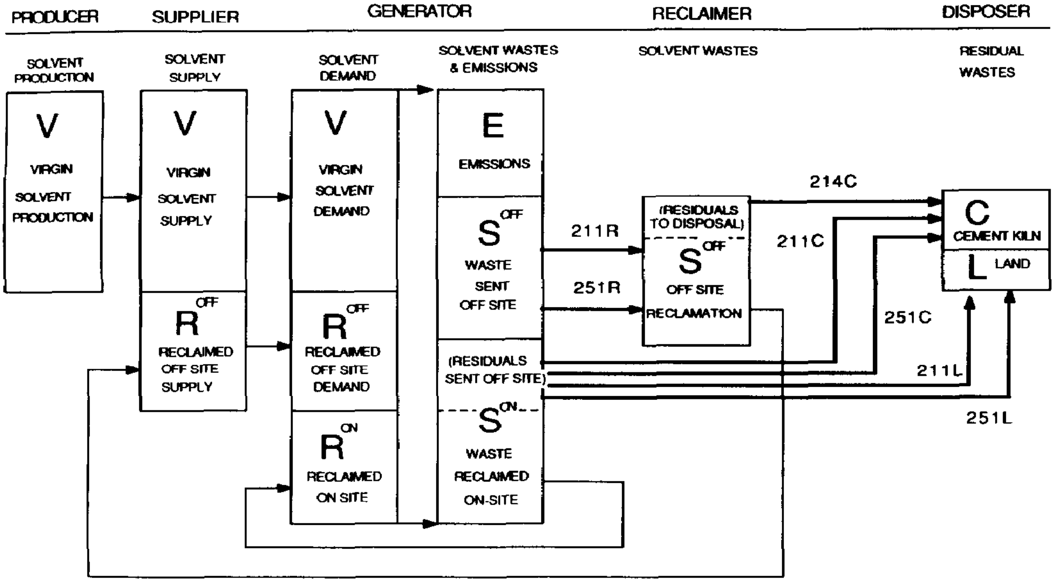

Fig. 1. Diagram of halogenated solvents materials balance (not drawn to scale).

level of *solvent reclamation* is the quantity of these solvent wastes that are reclaimed. The residuals from the reclamation process comprise the *residual* wastes that require hazardous waste *disposal* by such methods as fuel blending and land disposal. Finally, the amount of solvent wastes and residual wastes that are shipped off site is the level of *transportation* that is measured by the manifest system. The materials that enter the model as virgin solvent production equal the materials that exit the model as emissions or disposal in land or the cement kiln.

All of these distinctions can be made explicit in the model. For example, we can see that if reclamation were to shift off site, the manifest values for transportation could increase. With the materials balance model in mind, we could avoid the erroneous conclusion that solvent waste generation has increased. If on-site reclamation and solvent waste generation were to increase at the same time, there might be no change in the manifest data. Instead there might be a change in the solvent concentrations in the manifest waste streams, which can be represented in the materials balance model by changing a parameter value.

The materials balance model in practice

Computing the materials balance requires a number of heroic assumptions which are based on objective and subjective information from commercial reclaimers and disposal facilities. Furthermore, the results can only be as accurate as is the manifest data base. Hence, the results below are not presented as definitive precise estimates, but rather as reasonable ball park estimates. Discussion and details can be found in the supplementary Appendices available from the author.

Table 6 shows the 1988 materials balance for the major halogenated solvent waste streams in California. Note that all of these figures are quantities of halogenated solvent material, not the quantity of the entire waste stream. The only waste codes that were used were 211, 251, and 214, which capture the major waste streams for halogenated solvents. Waste code 214 is included because it is used by commercial reclaimers when they send their blend of solvents as fuel to the cement kiln. Code 214 wastes are relatively large quantities, but contain low concentrations of halogenated solvents.

We can see that the estimate for halogenated solvent to the cement kiln is only 434 tons in 1988. This is largely because the commercial reclaimers can reclaim roughly 97–98% of the recoverable solvent in the wastes they receive, and the residual "still bottom" contains only 5–12% halogenated solvent. The total off-site reclaimed solvent demand was about one fifth the demand for virgin solvent. Although solvent waste generation is estimated as 15730 tons, only 631 tons of residual wastes are generated after reclamation. If we consider the cement kiln as reuse, then only 197 tons of wastes were in need of disposal. Emission losses were 48312 tons, which is 98–99% of virgin solvent demand, or 76% of total solvent demand (including reclaimed solvent). The majority (94%) of waste transportation is solvent transported from generators to commercial reclaimers – the rest is transportation from the commercial reclaimers and on-site reclaimers to disposal.

One of the greatest sources of uncertainty in all of these estimates is the parameter for average concentration of halogenated solvent in the manifested wastes. The level of off-site reclamation is one of the better estimates because

TABLE 6

Materials balance for halogenated solvents in California, 1988 (tons)

Statistic	Halogenated solvent material
Materials to land disposal	197
Materials to cement kiln	434
Total residual waste generation	631
On-site reclamation	5875
Contaminated solvent to off-site reclamation	9855
Total solvent waste generation	15730
Emissions loss	48312
Virgin solvent demand	48943
Solvent reclaimed off-site demand	9609
Waste transportation	10486

the clear majority of halogenated solvent wastes that are reclaimed off site are transported as waste code 211. The estimate of total materials to the cement kiln is based on the manifest values summarized in the annual facility report. The level of on-site reclamation is probably underestimated significantly because it is estimated exclusively from 251 still bottoms, but the 211 waste code also includes a significant amount of residuals from partial reclamation.

Conclusions

The case of halogenated solvents can be considered a success story in terms of the land disposal restrictions and promotion of reclamation. The manifest data show clear evidence of the 1987 land disposal restrictions. All of the land disposal methods decreased dramatically for both 211 and 251 waste codes. Regarding California's 1985 land disposal restrictions, the evidence in the manifest data is less clear – perhaps because only free liquids were included and many of these wastes could be solidified. Since 1985, the proportion of 251 and 211 wastes that were transported to recycling has increased steadily.

The vast majority of spent halogenated solvents are reclaimed either on site or off site before their residuals are sent to the cement kiln. Ninety-three percent of all code 211 wastes and 66% of code 251 wastes that are transported are destined for "recycling" either by reclamation or fuel blending at the cement kiln. Of this transportation to recycling, 99% of 211 and 86% of 251 is transportation to commercial reclamation.

Solvent enters the materials balance model as virgin solvent demand and exits the model as either emissions to the atmosphere or reclamation residuals in need of disposal. Along the way the solvent is used and reclaimed over and over again. Of the total solvent used in a year – that is, the total demand including virgin and reclaimed solvent – about 76% is emitted to the atmosphere and 24% is generated as a hazardous waste, which is then reclaimed. In other terms, about 98–99% of virgin solvent demand eventually will be emitted to the atmosphere, and about 1–2% will be generated as residuals from the reclamation process, which are then blended with fuel at the cement kiln.

It is important to note that the high percentage emissions is *not* necessarily due to poor emission controls, but rather to the very high level of reclamation. The high level of reclamation reduces generation of waste residuals to such an extent that it is very small compared to emitted solvent. A high level of reclamation also means that more cleaning services can be done with the same amount of solvent before it is emitted. In contrast, a high level of emissions control means that less solvent is emitted and less solvent is used, but the level of waste generation is not affected.

It is difficult for government and industry officials to make policies based on the manifest system because of problems with waste code definitions, errors, and data interpretation. These difficulties are not unique to the California manifest system, and can be expected when analyzing hazardous waste data from other states or countries.

Acknowledgement

The author acknowledges and thanks Dr. Kathleen Wolf of the Source Reduction Research Partnership for her assistance with this project.

References

1 Chemical Marketing Reporter (CMR), Chemical Profiles, January 23, January 30, February 6, February 20, March 13, 1989.
2 Kirk-Othmer, 1979 and 1985, Concise Encyclopedia of Chemical Technology, Wiley, New York, NY.
3 K. Wolf and F. Camm, Policies for Chlorinated Solvent Waste: An Exploratory Application of a Model of Chemical Life Cycles and Interactions. The RAND Corporation, R.3506-JMO/RC. Santa Monica, CA, June, 1987.
4 Federal Register, 45 FR 12722, February 26, 1980. Government Printing Office, Washington, DC.
5 Federal Register, 45 FR 33221, May 19, 1980. Government Printing Office, Washington, DC.
6 Federal Register, 49 FR 10490, March 20, 1984. Government Printing Office, Washington, DC.
7 Title 22, California Code of Regulations, Section 66475. Barclay, San Francisco, CA, 1989.
8 Title 22, California Code of Regulations, Section 66530. Barclay, San Francisci, CA, 1989.
9 Title 22, California Code of Regulations, Section 66160. Barclay, San Francisco, CA, 1989.
10 U.S. Code of Federal Regulations, 40 CFR, Section 261.31.
11 California Department of Health Services, Hazardous Waste Information System Command List (CLIST) Reports, AB 2948 (Tanner) Reports, Sacramento, CA, March, 1989.
12 D.R. Steele, Los Angeles County Hazardous Materials Coordinating Committee, Los Angeles Times, November 25, 1984.
13 California Auditor General, The State's Hazardous Waste Management Program: some improvement, but more needs to be done, Sacramento, CA, November, 1983.
14 California Auditor General, The State's Hazardous Waste Management Program has improved in some areas; other areas continue to need improvement, Sacramento, CA, May, 1986.
15 California Auditor General, California's Hazardous Waste Management Program does not fully protect the public from the harmful effects of hazardous waste, Sacramento, CA, October, 1981.
16 California Governor's Office of Appropriate Technology, Alternatives to the land disposal of hazardous wastes, Sacramento, CA, 1981.
17 Title 22, California Code of Regulations, Section 66910.
18 Title 22, California Code of Regulations, Article 15.
19 California Assembly Office of Research, Toxic Ponds: antiquated methods, unacceptable dangers, Sacramento, CA, April 1984.
20 California Senate Office of Research, The buried threat: getting away from land disposal of hazardous waste, Sacramento, CA, March 1985.
21 Title 22, California Code of Regulations, Sections 66900–66905.
22 Toxic Pits Cleanup Act, 1984 (8 November?).

23 Federal Register, 51 FR 40572, November 7, 1986. Government Printing Office, Washington, DC.
24 Federal Register, 51 FR 1605, January 14, 1986. Government Printing Office, Washington, DC.
25 Federal Register, 51 FR 40579, November 7, 1986. Government Printing Office, Washington, DC.
26 Federal Register, 53 FR 31140, August 17, 1988. Government Printing Office, Washington, DC.
27 Federal Register, 50 FR 40605, November 7, 1986. Government Printing Office, Washington, DC.
28 Title 22, California Code of Regulations, Section 66763 and 66796. Barclay, San Francisco, CA, 1989.
29 California Auditor General, The State can do more to encourage alternatives to the land disposal of hazardous waste, improve waste classification, and pursue federal funds for site cleanups, Sacramento, CA, January, 1987.
30 California Department of Health Services, Recycling of Hazardous wastes in California, Sacramento, CA, January, 1988.
31 Governor's Task Force on Toxics, Waste and Technology, Report of Committee on Technical Considerations, State of California Governor's Office, March, 1986.

Additional reading

California Commission on State Government Organization and Economy, A review of the Organization and Management of the State Superfund Program for Cleaning Up Hazardous Waste Sites, Sacramento, CA, July 1984.

California Department of Health Services, Report to the Hazardous Waste Management Council. Toxic Substances Control Division, Hazardous Waste Management Branch, Sacramento, CA, August 31, 1982.

California Department of Health Services, Toxic Substances Control Division, Alternative Technology & Policy Development Section, Recycling and/or treatment capacity for hazardous wastes containing halogenated organic compounds, Sacramento, CA, November, 1984.

California Department of Health Services, HWCA Financing. Memorandum to Allen Zaremberg from Dave Willis, Sacramento, CA, March 13, 1986.

Governor's Task Force on Toxics, Waste and Technology, Final Report: Vol. 1. State of California Governor's Office, Sacramento, CA, May 1986.

Meredith/Boli and Associates, Inc., Review of the OAT reporting and related documents, Prepared for the Chemical Manufacturers Association, Meredith/Boli: Beverly Hills, January, 1982. (Cited in Morell, 1983.)

D.L. Morell, Technological policies and hazardous waste politics in California, in: J. Lester and A. Bowman (Eds.), The Politics of Hazardous Waste Management. Duke University Press, Durham, NC, 1983.

Southern California Hazardous Waste Management Project, Hazardous waste generation and facility development requirements in Southern California. Los Angeles Sanitation Districts, July, 1983.

Southern California Hazardous Waste Management Project, A Consumer's Guide to Hazardous Waste. Southern California Association of Governments, February, 1985.

University of California-Davis, Chemical Engineering Department, Hazardous Wastes in California: On-site Storage, Treatment and Disposal, 1982.

University of California-Davis, Chemical Engineering Department, Developing a Hazardous Waste Inventory Using Waste Stream Description Reports, April 1988.

U.S. Code of Federal Regulations, 40 CFR Parts 263-5, July 1, 1988, edn., Government Printing Office, Washington, DC.

Appendix A

Supplementary tables for waste codes 211 and 251

TABLE A-1

Waste code 211: proportion of total disposal

Disposal method	1984	1985	1986	1987	1988
Injection well	0.01	0.00	0.00	0.00	0.00
Landfill	0.07	0.05	0.11	0.04	0.02
Land application	0.01	0.00	0.00	0.00	0.00
Surface impoundment	0.03	0.17	0.04	0.01	0.00
Other	0.06	0.07	0.08	0.04	0.02
Recycle	0.76	0.51	0.56	0.69	0.79
Tank treatment	0.00	0.00	0.01	0.02	0.01
Treatment pond	0.00	0.01	0.00	0.00	0.00
Thermal treatment	0.00	0.00	0.08	0.04	0.01
Neutralization	0.01	0.00	0.00	0.00	0.00
Filtration	0.00	0.00	0.00	0.00	0.00
Stabilization pond	0.00	0.00	0.00	0.00	0.00
Unknown	0.05	0.18	0.12	0.17	0.15
Total	1.00	1.00	1.00	1.00	1.00

TABLE A-2

Waste code 251: proportion of total disposal

Disposal method	1984	1985	1986	1987	1988
Injection well	0.06	0.00	0.00	0.00	0.00
Landfill	0.20	0.22	0.24	0.00	0.00
Land application	0.08	0.01	0.00	0.00	0.00
Surface impoundment	0.03	0.01	0.20	0.01	0.00
Other	0.18	0.30	0.12	0.00	0.00
Recycle	0.18	0.06	0.06	0.33	0.45
Tank treatment	0.00	0.00	0.00	0.01	0.00
Thermal treatment	0.20	0.04	0.00	0.20	0.22
Unknown	0.07	0.37	0.39	0.45	0.32
Total	1.00	1.00	1.00	1.00	1.00

APPENDIX A (*continued*)

TABLE A-3

Waste code 211: percent change from previous year

Disposal method	1984–85	1985–86	1986–87	1987–88
Injection well	−1.00	ERR	ERR	ERR
Landfill	−0.06	1.12	−0.72	−0.65
Land application	−1.00	ERR	−1.00	ERR
Surface impoundment	6.05	−0.78	−0.84	−1.00
Other	0.48	0.02	−0.59	−0.56
Recycle	−0.12	0.08	−0.10	0.03
Tank treatment	ERR	1.35	0.18	−0.29
Treatment pond	ERR	−1.00	ERR	−1.00
Thermal treatment	0.16	49.90	−0.65	−0.75
Neutralization	−0.45	−1.00	ERR	−1.00
Filtration	ERR	−1.00	ERR	ERR
Stabilization pond	ERR	ERR	ERR	−1.00
Unknown	3.32	−0.32	−0.02	−0.16
Total	0.30	−0.02	−0.26	−0.10

TABLE A-4

Waste code 251: percent change from previous year

Disposal method	1984–85	1985–86	1986–87	1987–88
Injection well	−1.00	ERR	ERR	ERR
Landfill	0.33	0.30	−0.99	−0.29
Land application	−0.92	−1.00	ERR	ERR
Surface impoundment	−0.63	28.39	−0.96	−1.00
Other	1.12	−0.53	−1.00	4.00
Recycle	−0.61	0.28	2.69	−0.25
Tank treatment	ERR	ERR	ERR	−1.00
Thermal treatment	−0.78	−1.00	ERR	−0.37
Unknown	5.80	0.26	−0.24	−0.60
Total	0.24	0.21	−0.35	−0.45