USING POLLUTANT RELEASE AND TRANSFER REGISTER DATA IN HUMAN HEALTH RESEARCH: A SCOPING REVIEW

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Complete List of Authors:
- Wine, Osnat; University of Alberta, Paediatrics
- Hackett, Cian; University of Alberta, Paediatrics
- Campbell, Sandy; University of Alberta, John W. Scott Health Sciences Library
- Cabrera-Rivera, Orlando; Commission for Environmental Cooperation, Air Quality and Pollutant Releases
- Buka, Irena; Stollery Children's and Misericordia Community Hospitals, University of Alberta, Paediatrics
- Zaiane, Osmar; University of Alberta, Computing Sciences
- DeVito, Stephen; Environmental Protection Agency, Toxics Release Inventory Program
- Osornio-Vargas, Alvaro; University of Alberta, Pediatrics

Keyword: pollutant release and transfer register, PRTR, human health, industrial emissions, toxic chemical releases
USING POLLUTANT RELEASE AND TRANSFER REGISTER DATA IN HUMAN HEALTH RESEARCH: A SCOPING REVIEW

Authors: Osnat Wine\textsuperscript{1}, Cian Hackett\textsuperscript{1}, Sandy Campbell\textsuperscript{2}, Orlando Cabrera-Rivera\textsuperscript{3}, Irena Buka\textsuperscript{1,4}, Osmar Zaiane\textsuperscript{5}, Stephen C. DeVito\textsuperscript{6}, Alvaro Osornio-Vargas\textsuperscript{1}

\textsuperscript{1} Children’s Environmental Health Clinic (ChEHC), Department of Paediatrics, University of Alberta, Edmonton Clinic Health Academy, 11405 87th Avenue Edmonton, Alberta, Canada. T6J 1C9

\textsuperscript{2} John W. Scott Health Sciences Library, 2K3.28 Walter C. Mackenzie Health Sciences Centre, University of Alberta, Edmonton, Alberta, Canada. T6G 2R7

\textsuperscript{3} Air Quality and Pollutant Releases, Commission for Environmental Cooperation, 393, rue Saint Jacques, Suite 200, Montreal, Quebec, Canada. H2Y 1N9.

\textsuperscript{4} Stollery Children’s and Misericordia Community Hospitals, Child Health Clinic, Mother Rosalie Health Services Centre, 231-16930 87 Avenue NW, Edmonton, AB, Canada. T5R 4H5,

\textsuperscript{5} Department of Computing Sciences, 443 Athabasca Hall, Department of Computing, University of Alberta, Edmonton, Alberta, Canada. T6G 2E8

\textsuperscript{6} Toxics Release Inventory Program (mail code 2844T) U.S. Environmental Protection Agency, 1200 Pennsylvania Avenue, NW, Washington, D.C. 20004, USA.

Corresponding Author:
Dr. Alvaro Osornio-Vargas
Department of Paediatrics
ECHA 3-591 11405 87th Ave, NW,
ABSTRACT
Pollutant Release and Transfer Registers (PRTRs) collect and provide information on chemicals released to the environment or otherwise managed as waste. They support the public’s right-to-know and provide useful information in gauging performance of facilities, sectors and governments. The extent to which these data have been used in research, particularly in relation to human health, has not been documented. In this scoping review our objective was to learn from scholarly literature the extent and nature of the use of PRTR data in human health research. We performed literature searches (1994-2011) using various search engines/key words. Articles selected for review were chosen following predefined criteria, to extract and analyse data. One hundred and eighty four papers were identified. Forty investigated possible relations with health outcomes: Thirty-three of them identified positive associations. The rest explored other uses of PRTR data. Papers identified challenges, some imputable to the PRTR.

We conclude that PRTR data are useful for research, including health-related studies and have significant potential for prioritizing research needs that can influence policy, management and ultimately human health. In spite of their inherent limitations, PRTRs represent a perfectible, unique useful source, whose application to human health research appears to be underutilized. Developing strategies to overcome these limitations could improve data quality and increase its utility in future environmental health research and policy applications.

Keywords:
Pollutant Release and Transfer Registries; PRTR; human health; industrial emissions; toxic chemical releases
INTRODUCTION

Pollutant Release and Transfer Register (PRTR) is the generic term used to describe a type of publically available database that contains information on the quantities of toxic chemicals or other pollutants released from industrial facilities or other businesses to air, water and land, or otherwise managed as waste (e.g. recycled, burned for energy recovery) within a given country. A PRTR is established and maintained by a country’s national environmental authority. The pollutant amounts reported to a PRTR are not always based on direct measurements, but are usually based on estimates. Estimated emission quantities are often derived from different methods including mass balance or engineering calculations, and emission factors relating a pollutant amount to production/activity levels. The accuracy of these depends on the available estimation methodology, and therefore may differ in the level of accuracy. These data are typically submitted to the authority maintaining the PRTR on a regular basis (usually annually) by facilities that are required to report such information. Some PRTRs also include estimates of releases from diffuse sources, such as agriculture, transportation and the end use of products (PRTR.net 2012).

The purpose of PRTRs is primarily to increase the public’s knowledge of, and access to, information on the releases and other waste management practices of toxic chemicals and other pollutants in their communities. This information: provides the public with knowledge on the dispositions of pollutants in their communities; help enable citizens to make informed decisions regarding the consequences of such dispositions; and enable citizens to take action.

Federal, regional, state, and local governments also use PRTR data for prioritization purposes. The development and implementation of a PRTR adapted to national needs assists governments in tracking the generation, release, and fate of emissions of toxic chemical substances and other
pollutants over time, examining progress in reducing emissions, and setting pollution prevention
and sustainability priorities.

Publically available PRTRs began to be established after the 1984 industrial disaster in Bhopal,
India, which sparked interest in community right-to-know programs (Harjula 2006). The United
States’ Toxics Release Inventory (TRI) was the first public PRTR. EPA published its first annual
TRI dataset in June of 1989, which pertained to toxic chemicals discharged from facilities in
1987 (EPA 2012b) (Environmental Protection Agency 1989).

Encouraged by the Organization for Economic Co-operation and Development (OECD) 1996
recommendation on implementing PRTRs (Harjula 2006), many other countries in most parts of
the world have since established and/or modified their own PRTRs. Currently, more than 50
countries have implemented a fully operational PRTR or pilot PRTR. Examples of other PRTRs
are: Canada’s National Pollutant Release and Transfer Inventory (NPRI), European Union’s
European Pollutant Emissions Register (EPER), Australia’s National Pollutant Inventory (NPI),
Mexico’s Registro de Emisiones y Transferencia de Contaminantes (RETC). More countries will
join the PRTR initiative in the coming years. International efforts to reduce health impacts from
toxic environmental chemicals have prompted the United Nations Institute for Training and
Research (UNITAR) to promote implementation of PRTRs in more countries (UNitar 2013).

Though PRTRs are defined internationally (PRTR.net 2012), and many are modeled after the
U.S.’ TRI, many of the existing PRTR systems vary widely from country to country, particularly
in the chemicals tracked, coverage of industrial sectors and activities, and in how emission and
other reportable quantities are determined. These differences can be ascribed to the fact that a
given country will engineer its PRTR within the boundaries of existing statutory authority and its
country-specific goals and objectives as the drivers behind the PRTR structure. As countries’
goals and objectives and environmental statutory differ, therefore so do countries’ resulting
PRTRs. The differences among PRTRs from different countries lead to comparability issues
when trying to compare or integrate data from the PRTR of one country with data contained in
the PRTR of another country (Kerret and Gray 2007).

As PRTR data are intended for a wide variety of users, including government agencies, industry
managers, scientists, community groups, and the general public, making this information
available to, and useable by these separate user groups is an ongoing priority of any PRTR
system (PRTR.net 2012). PRTR information is frequently made available through internet-based
tools that enable users to conduct analyses online, or in downloadable form for subsequent
analysis. As part of their periodic (e.g., annual) update with newly reported information, many
environmental authorities supplement the information with an official report that identifies trends
or other noteworthy observations and provides analyses of specific chemicals, sectors, and
geocoded locations of interest. Some governments publish interactive maps of the complete
database and some publish tools to create maps from the data, such as the U.S Environmental
Protection Agency’s TRI Explorer, TRI.net, and MyRTK tools (EPA 2012b). However, given
the ever-advancing field of information technology, and evolving needs of PRTR data users,
making the information available in its most useable forms is an ongoing priority.

Worldwide, the disclosure of routine emissions and transfer quantities of toxic chemicals to
PRTRs has been a major factor in the reduction of pollutant emissions generally observed in
countries that have PRTRs (Bui and Mayer 2003; Thorning 2007). Community groups have used
PRTRs to directly influence management of facilities in which concerns were identified (Jackson
Thus the PRTRs contribute to the public’s access to information and influence reductions in pollutant releases (Harrison 2003).

Policy makers, decision makers, and communities are concerned about negative health outcomes resulting from toxic chemical releases. PRTR data, in conjunction with additional information (e.g. pollutant characteristics), can provide starting points in the determination of potential impacts of these releases on human health. Identification and characterization of any causal associations between pollutants and health impacts require exposure assessments, ideally at the personal level and through the use of monitored data (Zou, Wilson et al. 2009). Nevertheless, this is not achievable at times when examining possible impacts of hundreds of chemicals, making PRTR emission data a source of surrogate chemical exposures for a comprehensive amount of chemicals in large population studies (Table 1), as part of a continuum in exposure assessment.

Beyond that, the potential economic impact associated with health risks can also be estimated. For example, in the Canadian province of Ontario total toxic pollution was positively related to per capita health expenditures. Future public health investment, therefore, should include environmental protection since this may potentially reduce health expenditures (Jerrett, Eyles et al. 2003). Using PRTRs as a tool, research may be able to identify potential causal relationships between pollution emissions and negative health outcomes within given localities. This provides decision makers with more evidence upon which to develop relevant policies intended to reduce negative health outcomes and their associated economic costs.
Utilizing PRTR data: In order to promote the proper use and applicability of PRTR data, most PRTR Programs, as well as organizations that embrace the usefulness of PRTRs (e.g., the OECD), have developed guidance documents, tools, and methods for utilization of the data. In addition, several groups have also developed user-friendly tools for individual and community use. Examples of such tools include:

- THE RIGHT-TO-KNOW NETWORK (RTKNET.ORG 2009);
- Scorecard: the pollution guide: GoodGuide (Scorecard 2011);
- CAREX CANADA Surveillance of environmental & occupational exposures for cancer prevention (CAREX 2012);
- Taking Stock Online, a North American integrated PRTR database developed by the Commission for Environmental Cooperation (CEC 2011);
- Centre for PRTR Data, a tool developed by the OECD through the United Nations Economic Commission for Europe (OECD)

However, the available tools for accessing data are generally insufficient for users who want to access non-aggregated data and to identify individual or community health risks (Hammond, Conlon et al. 2011). At a public meeting of the ‘North American meeting of the Commission for Environmental Cooperation’ North American PRTR project held in 2010 (CEC), concerns were raised about the lack of broad use of these data and the need for increased applicability and wider use of PRTR data.

While awareness of PRTRs may be high among environmental groups (Thorning 2007), it is very low among the general public with studies citing from 2% to 11% awareness level (Aoyagi 2007; Atlas 2007; Thorning 2009). These findings may relate to peoples’ indifference or to the complexity of the data and the clarity of their relationships with health outcomes. In spite of the
development of various tools, communities still need expert assistance to interpret and to translate the data into a usable form (Hammond, Conlon et al. 2011).

Interested in the use of PRTR data to investigate associations between pollution and human health outcomes, we performed preliminary searches identifying a limited number of peer-reviewed articles. Therefore, we decided to expand the search to encompass all uses of PRTR aiming to mine the scholarly literature in order to characterize the extent and nature of the use of PRTR data in human health-related research, and evaluate its usefulness in such research. Specifically, the objective of this paper is to identify and examine the range and nature of the scholarly literature in which the scientific community has used PRTR data (particularly in association with human health outcomes), summarize and disseminate our research findings, and identify research and knowledge gaps. Our findings may also guide improvements to PRTR data reporting. Improved data could be used to promote advancements in environmental management leading to reductions in emissions of harmful substances and support decision-making related to human health and the environment.

THE SCOPING REVIEW PROCESS

We chose to undertake a scoping review given the relatively undeveloped state of this field of research and limited comparability among publications that used PRTR data, following Arksey and O’Malley’s framework (Arksey 2005).

Data selection process:

Papers were included if they used PRTR data. Only English language, peer reviewed works (including conference proceedings, books and theses, but not reports) were included, and only
those for which full text was available. Date limits were established by the dates of the initial
release of the first PRTR in 1988 (i.e. US TRI). We selected documents published before July
2011.

1. As a first step, we used a broad research theme that assisted in identifying relevant literature
from a variety of resources and included both qualitative and quantitative studies in our results.
Various search techniques and terms were used to maximize potential findings. Keywords were
used individually or in combination and included:
(PRTR, “pollution release and transfer”, “release and transfer reg**”, “toxics release inventory”)
(medic*, health*, pediatric, illness, wellness, cancer, carcinoma, paediatrics*, asthma, copd).
These searches were later broadened and refined to include: (toxics release, npri, national
pollut*, pollut* release) (simulate, dispers*, model, analys*, develop*, design*, understand*,
evaluat*, indicat*, appl*, validat*, verif*, research, systematic) NOT (National Pollutant
Discharge Elimination System). Where appropriate controlled vocabulary terms, such as those in
the Medical Subject Headings (MESH) were also searched.
Databases included: Compendex, EMBASE, Environment Abstracts, GEOBASE, Global Health,
MEDLINE, Pascal, Pollution Abstracts, and Scopus. Proquest Dissertations and Theses
Databases were searched for works containing TRI or PRTR and related terms. As many studies
did not document the US’s TRI as a PRTR, searches for TRI and health terms in MEDLINE and
Scopus were performed. To capture further applications of PRTR data, Environment Abstracts,
Pollution Abstracts, TOXLINE/toxicology, and Water Resources Abstracts were searched, using
terms related to pollutant and toxic releases.

2. In order to ensure the search was comprehensive, we undertook a second step, searching for
additional publications in the citations of the papers identified in stage one as using PRTR data to
examine the relationship with health outcomes. We added any new articles that fit the inclusion criteria to this study. All identified references were stored in the RefWorks citation management system.

RESULTS OF THE SCOPING REVIEW

Stage I: We identified 1318 records through database searches and hand searching. Cited reference searching identified 28 additional publications (Citations were checked for health outcomes only, due to the limited numbers of identified publications).

Stage II: After removing duplicates, 867 publications were screened. One reviewer screened the publications, using the inclusion/exclusion criteria defined above.

Stage III: In the second screening, one reviewer read 342 articles in full and those that met inclusion/exclusion criteria were selected. In cases of uncertainty whether or not a publication met the criteria, a second reviewer evaluated them. Searches and data handling were recorded.

Stage IV: 184 references fit the inclusion criteria and were included for synthesis. Paper selection was documented according to the PRISMA flowchart (Figure 1). This figure describes the overall flow of the scoping review literature search and publication selection process. Data extracted from the studies included: the study year, type of work, origin country of the PRTR data used, year of PRTR, chemicals, the study’s objective, methods, outcomes studied, results, and identified limitations of PRTRs. Data were recorded in Excel spreadsheets and later formatted into evidence tables to manage the data and to chart key patterns and themes.

Two readers sorted these publications to the following two groups then:

1. Peer-reviewed studies that investigated PRTR data and actual human health outcomes data.
Peer-reviewed studies that investigated PRTR data and any other outcomes, or described other uses of the data.

Publications from both groups were then researched for challenges and limitations.

Only 184 of 1346 found documents met all selection criteria. Of the 184 documents, only 40 examined for associations between PRTR emissions with human health outcomes, and an additional 144 used PRTR data in other research undertakings. The identified publications included primary research articles, dissertations and theses and conference proceedings. These publications had diverse objectives and used a wide variety of methodologies. The earliest identified studies were published in 1993. Publication output followed an erratic upward pattern in time until 2009, when a downward tendency started to occur (Figure 2).

The extent, range, methods, and challenges identified are presented below, grouped by:

a) Human health outcomes
b) Other uses
c) Challenges and limitations

a) Human Health Outcomes

Our search identified 40 publications that described research aimed at identifying relationships between industrial emissions of toxic chemicals and other pollutants (as quantified in the form of PRTR data) and adverse effects on human health.

PRTR by country: of these studies, 34 (85%) used the TRI as the PRTR data source. The PRTR systems of other nations accounted for the remainder: five from the Spanish portion of the
European Pollutant Emission Register (EPER) and one from the UK’s National Atmospheric Emissions Inventory (Table 1).

Years of publications: ranged between 1997-2011 (Figure 2). Publications started to appear in 1993, several years after the first PRTR was established. Although increasing numbers of publications were found, the distribution is erratic. It was not until 1997 that health related studies started to be published. Health studies were sparse before 2004, and their rate of publication increased in the following years.

Health outcomes studied: Of the identified studies, 24 (60%) investigated whether relationships exist between PRTR-related emissions and cancer incidence. Other health outcomes investigated include: negative birth outcomes, population mortality rates, neuro-developmental disorders, and other specific conditions (e.g. multiple sclerosis, asthma, and mental illness) (Table 1). Fourteen papers focused on child or maternal exposure (Figure 3).

Chemicals: The chemicals studied in the identified research varied (Table 1). Some used all reported emissions, while others used: chemical releases from specific industry sectors (such as manufacturing, paper and pulp, combustion facilities, metal production, petroleum refiners, or all industries) (Table 1). Some studies used chemicals that are known to cause a specific toxic effect (such as cancer or developmental toxicity), single chemicals (such as benzene, lead, or mercury), or a group of chemicals (e.g. metals, volatile organic compounds). Three further publications considered the location of PRTR reporting facilities to investigate health risk areas.

Methods and Results: More than half (22) of the papers described the use of one or more of a variety of statistical analyses and Geographic Information System (GIS) methods. The statistical methods used include: linear regression, Poisson regression, and Bayesian approaches. It was not possible to discern a specific pattern in the choices of statistical methods used. Most of the
studies (33 out of 40, 82%) reported associations of varying strength between health outcomes and emission and seven papers reported no health associations.

b) Other Uses

In this category 144 publications were identified (Table 2).

PRTR by country: 93 publications used the TRI as the PRTR data source, 19 used Japan’s PRTR, 11 used Canada’s National Release and Transfer Inventory (NPRI), 6 used the European PRTR data, 6 used Australia’s NPI, and 1 used Mexico’s RETC. Eight studies compared data from more than one PRTR (US, Japan, Canada, Australia, Mexico, United Kingdom, Korea, and Europe).

Years of publication: studies were published between 1993 and 2011 (Figure 1). Increased numbers of publications started after 1995 with variations over time.

Chemicals studied: 79 studies looked at general emissions while 65 others looked at a specific chemical or groups of specific chemicals.

Other uses of PRTR data: publications have used PRTR data for diverse objectives (Table 2). Many of the publications used one or more of the objectives listed in Table 2 (when studies fit into more than one category, they were classified by the main theme). This indicates the complexity of this field of research. In general, studies evaluated potential risk for human health (e.g. cancer) based on chemical characteristics only and not health outcomes, or assessed the impact of the potential health risk on housing market, corporate values, etc. Other studies assessed trends in chemical releases, evaluated emissions, and the environmental performance in response to different policies, public pressure, or changes in management. Still, other studies investigated the accuracy of the data presented, and chemicals’ measurements and characteristics.
(i.e. flow, exposures, risk impact). The data were also used to describe demographics around facilities, including socio-economic variables, to examine possible relationships between emissions and other social variables. Lastly, some of the papers investigated awareness among members of the public about PRTRs and possible uses by communities.

Methods and presentation of results: The publications identified used a variety of analytic methods, such as: advanced statistic analysis, simple analysis using trends, comparisons, measurements, GIS (36 papers), and various modelling systems. There were at least 25 studies that focused on describing research tools, research models, or different methods to analyse PRTR data.

The studies used different tools and venues to present their research. These included the use of GIS or maps, human health index/toxicity index, websites, books/papers, public and government meetings and discussions, online tools, chemical rankings and formation of management frameworks.

c) Challenges and Limitations

This field of research is challenged by the data itself, as detailed in Table 3 and Table 4. The majority of publications (172 out of 184) identified limitations attributed either to research design, lack of supporting data, or to limitations imputable to the PRTR data. These limitations mainly included difficulties with data accuracy, quality, and completeness. Authors identified data quality/completeness issues that could affect the results of the data analysis such as: lack of non-threshold emissions reporting, under-reporting, change in reporting requirements over time, and lack of tracking for all chemicals in use (Table 3).
Other identified limitations could be imputed to study design or the lack of supporting data (Table 4), including: the lack of use of confounding variables, such as demographic and socio-economic variables (major confounding) or other sources of exposures (i.e. occupational exposures, traffic, smoking - in the case of health studies). Other limitations relate to the lack of information of potential risk to human health from emissions tracked in PRTR; the lack of chemical dispersion estimations; and problems related to the frequent modifications of geographic unit areas that rely on the number of individuals living in those areas. In the health outcomes studies a specific limitation was identified relating to the lag time between exposure and health effects.

DISCUSSION

The objectives of this scoping review were to assess the use of PRTR data with specific focus on health related studies and to identify objectives and challenges of this type of research. In order to have a complete picture of research publications that used PRTR data, the different methods and challenges found in all publications using PRTR data were included in the analysis of results.

The impact of emissions of toxic chemicals on health is well documented. Even low-level chronic exposures to some chemical pollutants have been implicated as contributors to the increase and prevalence of diseases or illnesses such as cancer; negative developmental and birth outcomes; asthma; and neuro-development delay (Boeglin, Wessels et al. 2006; Whitworth, Symanski et al. 2008; Bose-O'Reilly, McCarty et al. 2010; Mattison 2010; Rusconi, Catelan et al. 2010). The economic cost of ill health due to pollution is estimated to be substantial (Jerrett, Eyles et al. 2003; Agarwal, Banterngansa et al. 2010). The identification of the impact of
environmental pollution on human health and sustainable development has created the need to
monitor and account for emissions and transfers of pollutants.

A total of 184 publications were identified in our research, and these publications had various
applications and objectives. We divided these into two general categories: human health
outcomes studies (40 publications) and other uses studies (144 publications).

Time range and extent of publications:

We identified papers starting at 1993, six years after the initiation of the first PRTR, the US TRI.
Research publications that examined health outcomes began to appear four years later. This
could be attributed primarily to the inherent lag time between receipt of the data by the agency,
processing and release of the data by the agency to the public, time needed to conduct research,
and publication of the research results. Another contributing factor could be the general lack of
awareness of PRTR datasets among researchers. The interest in and use of data increased
through subsequent years and continues as such. For example, our findings identified 24
published theses, which reflect the incorporation of PRTR data into training of new researchers.

There was an overall small increase in the number of publications per year, more evident in the
health outcomes category. This may indicate that health research using PRTR data is a growing
field.

Origin of publications:

Many countries were represented in the identified publications, though most of these studies used
the US TRI dataset and where published by researchers from U.S.-based organizations. In the
health outcomes category there is a notable absence of publications from research groups based
in countries such as Canada, Australia, and Japan, which were found to be more active in
publication of other uses of PRTR data. The exclusion of non-English language studies may have
affected our study’s findings. Another possible cause may relate to the fact that the US TRI was
the earliest PRTR and users of TRI data have had more time to develop research methodologies
and optimize the data for analysis. In addition, the US TRI has been actively developing tools to
assist users with data analysis and incorporating tools to easily cross-reference with other
environmental databases or registries (National Emissions Inventory, Envirofacts, Facility
Registry System, etc.) (EPA 2012c). The lack of publications could also be due to lack of
awareness in the public and the scientific communities of the availability of the data. It may also
reflect the relative sizes of the environmental health research communities in each country, or the
availability of support and funding of this kind of research.

Compared to other PRTR datasets, the relatively wide use of the US’ TRI to identify possible
associations between industrial emissions of toxic chemicals with human health impacts
demonstrates that the same kind of study could be done with other PRTR datasets, recognizing
that the specific characteristics of a given PRTR would need to be addressed.

Data uses, methods and methodologies:

We identified a wide range of uses of the PRTR data indicating that the data may be useful in
answering various types of research questions. Nevertheless, further research will need to assess
the impact of PRTR-based research on local policy and practice, much like the recent study
undertaken by the US Environmental Protection Agency’s (EPA) TRI Program. The study
identified EPA-funded research from 1995-2010 that involved the use of TRI data and all
corresponding publications, analyzing the use of TRI data and the outcome(s) of the research.
(EPA 2012a).
Some of the papers identified in the present study also offered methods or methodologies that may be useful when using PRTR data in research and assessing impacts.

In the health outcomes category, a large number of the studies found a statistically significant positive correlation between pollutant releases and negative health outcomes. It is not clear if a particular analytical methodology is more likely to find significant relationships. Conley (Conley 2011) claims that the use of different methods of analysis can give different results about the impact of pollution on health outcomes and that the most reliable estimates did not always result from using complex methods.

Additionally, models of exposure need to consider factors such as chemical properties and behaviour in the environment, meteorological conditions, and local topography. Therefore, assessment of actual or potential health impacts from routine industrial emissions or other transfers of chemicals into the environment requires a combination of different research methodologies as part of a continuum in exposure assessment and as indicated in several of the reviewed papers.

Health outcomes and age:

Many studies focused on cancer incidence. This may be because there are known relationships between industrial emissions of carcinogenic chemicals and incidences of cancers in humans. It may also relate to the fact that health data are easier to retrieve from cancer registries. Some studies investigated other health outcomes, demonstrating the future usefulness of PRTR data in various kinds of health research (Table 1). We also analysed age groups that were studied and found that 14 out 40 papers focused on children. There is an increased interest in children’s
health research since children are often more susceptible to exposure to chemicals and, with
some chemicals, are also more sensitive to the toxic effects they cause. However, funding
directed towards prevention and health outcomes research in children has been declining (Hay,
Gitterman et al. 2010). Our findings show some increase in the total number of studies looking at
health outcomes in general but not a specific increase in research focused on health outcomes in
children.

**Limitations identified by authors of the reviewed publications:**
The majority of publications acknowledged some limitations in their research, which were
divided into two categories: 1) limitations that were imputable to the PRTR data and, 2)
limitations imputable to study design.

1) Many of the limitations referred to the type, quality, and accuracy of the data. Lack of
“non-threshold” emissions of toxic chemicals (i.e. emissions that are not reported because
a reporting threshold was not triggered) and the inclusion of a limited number of
chemicals are some examples identified as limitations affecting the research. Some
studies have addressed this by estimating non-threshold emissions using different
techniques, based on productivity ratios or labour use ratios, or assuming average
emissions of a percentage of the threshold. Most PRTRs track the more toxic chemicals
used in commerce, but the respective chemicals regulated by at least some PRTRs have
changed through the years. Not infrequently, a given environmental authority will expand
or decrease the number of chemicals regulated by its PRTR program, as societal priorities
change or additional information on such chemicals becomes available. Such changes can
confound research aimed at using the information collected by the PRTR as a data
source, unless normalization is made for such changes in chemical coverage. Other
limitations referred to accuracy and inclusion criteria for reporting of the data. Even
errors in the location of the emitting facilities (e.g. address provided corresponds to
headquarters and not to the emitting facility, inaccurate geocoding) were identified as an
obstacle in obtaining accurate results (Garcia-Perez, Boldo et al. 2008). While infrequent,
threshold levels for reporting emissions or other waste management quantities on one or
more chemicals change, or industry exemptions are added or removed. For example, in
1994 the US EPA finalized a regulatory action that greatly increased the number of
chemicals regulated under its PRTR (the TRI). In 1997, the US EPA finalized a
regulatory action that expanded the types of facilities required to report emissions and
other waste management quantities of toxic chemicals to the TRI. In the year 2000, the
thresholds that triggered reporting of toxic chemicals that also persist in the environment
and bioaccumulate in the food-web were greatly lowered. (Currie and Schmiede 2009).
These actions, while they greatly expanded the information collected by the TRI, can
confound research investigations unless these changes are taken into account during the
investigations. For example, researchers can normalize for changes to the chemicals
regulated by a given PRTR by using core chemicals (chemicals which have been
regulated by the PRTR throughout the years), or by only using data from years after
reporting has stabilized. In some instances, such changes have driven some municipalities
to develop their own requirements (e.g. the province of Ontario, Canada after deeming
the NPRI requirements to be insufficient (MOEE 2010)). The factors described above
and those imputable to study design further emphasize the need for scholarly research, as
was noted by many studies.
Many of the studies included the need to incorporate confounding variables e.g. socio-economic and demographic. Another commonly cited limitation was lack of toxicity equivalents that can provide an indication of potential risk. Lack of toxicity equivalents, instead of absolute amounts emitted, remains a limitation in many papers, although, some offer data converted to a human health index. For chemicals that are structurally similar and cause the same toxic effect, but vary in their potency (i.e. dose needed) to cause the effect, toxicity equivalents are useful for facilitating the estimation of the cumulative risk posed by emissions of multiple congeners of the chemical class. Toxicity equivalents are generally based on the assumption that congeners in the series cause the toxic effect through the same biochemical mechanism, and the toxic potency is normalized through the equivalency.

Some authors (Coyle, Hynan et al. 2005; Boeglin, Wessels et al. 2006; Luo, Hendryx et al. 2011) identified that lack of data for describing the time lag between exposure and onset of harmful health effects is an inherent difficulty in PRTR health outcome research. Other authors considered that this factor is addressed when studying child health outcomes. Agarwal et al. chose to focus on health effects in infants under one year and over 20 weeks in utero. By doing so, they avoided the proxy estimates for life time exposure levels (Agarwal, Banterng hansa et al. 2010). However, the effect of an exposure lag in studies that included children up to age 18 may be very different from the effect of a lag in studies that included only children up to age 5. Limitations referred also to aggregation of population data, exposure data and the Modified Areal Unit Problem (MAUP) (Openshaw 1984) (Table 4). Privacy concerns often require the use of
aggregated data, at the level of relatively large government administrative defined areas, such as the census tract, states/provinces or country. The differences of the resolutions of the data derived from PRTRs (point location: longitude/latitude) and government sources may make comparison impossible. This creates the problem of changing results and correlations when different spatial units are used (MAUP). For example, using data at the county level versus the state level yields different results. MAUP may be addressed in study design by using a variety of different areal units if the data allows.

Though there are limitations to the PRTR data there are researchers who use the geocoded data for various research objectives and for examining health outcomes in particular.

Limitations of this literature review:

A limited number (forty) of health outcome-related publications were identified in the present study. While half of the references to these publications were found by an extensive search in databases using various key words and search engines, the other half were identified by a manual search. International PRTRs are often referred to by its national name and not by PRTR, and though some searches were done for the US’s TRI, searches were not done for all name-variants in all languages and thus the keyword search may not have captured all studies, inevitably missing some publications. Indexing services are also slow to create controlled thesaurus terms in new areas, so articles may be only indexed to broader terms. Another limitation of this literature review was the inclusion of English literature only, though PRTR data is national and many nations publish in different languages. Foreign language databases were not searched. Future research may benefit from the application of a systematic review to examine health outcomes using PRTR data.
Potential uses of PRTR data in the future:

New research methods such as data mining, land use regression models and interdisciplinary methods could be used to minimize limitations imputable to study design. Through the inclusion of a larger number of variables and particularly socio-economic variables (which was identified as one of the major missing confounders) limitations can be further minimized. Interdisciplinary research could identify chemicals and mixtures of chemicals, which may potentially affect human health and may need to be mandated for scrutiny. Interdisciplinary research can also support the identification of associations with emerging health conditions (e.g. obesity, neurodevelopmental, etc.). While researchers have begun to use PRTR data in investigation of health outcomes there is definitely room for expanding the use of these valuable data in future research and support future local planning and decision-making.

Other improvements that could increase the use of the PRTR information include raising awareness of the existence of such databases and improving translation of the data to usable forms. Effective translation of the synthesized data should be an essential part of the PRTR agenda. It would require experts’ knowledge to translate the collected data for environmental regulators; the medical research community, health care providers and public health officials to develop an action plan for an area of concern (Maantay 2002; Bae, Wilcoxen et al. 2010).

Worldwide, many resources have been invested in the development of PRTR systems. These registries have collected data since 1988 with the first health related publication using these data published in 1997. Our study has revealed that while the data and methods of analyses have limitations, the publication record shows the value of the data in research. There needs to be significant improvement in the quality of the data to create a powerful tool for these valuable
data to be fully exploited. While the research output is currently small the volume of the data being collected holds huge potential for research that can influence public policy, environmental management practices, and ultimately human health. These findings will support future research by identifying limitations currently impacting the effective use of these data.

CONCLUSIONS

This scoping review has identified 184 scientific publications that used PRTR geocoded data to either investigate possible health outcomes or for other uses. While this number may appear small relative to the total number of scientific papers published over the same time interval, the number of human health-related publications that involve the use of PRTR data has generally increased through the years, reflecting a growing interest in this field of research. Moreover the various uses of the PRTR data we found demonstrate the potential for a range of research studies using these data (such as association between pollutants and various health outcomes). For example, the use of PRTR data in a variety of research based on the US TRI illustrate that PRTR datasets are useful information sources and supports the idea that these datasets are a valuable research resource. However, it is clear that these data offer many more research opportunities than those that had already been explored. We have identified that there is a gap in knowledge that could be obtained from PRTR data, as a result of low exploitation of the data, as was previously identified (EPA 2012a). This knowledge gap may be attributed to the fact that this is a relatively new and evolving field of research, or relate to the complexity of this type of research and the multiple considerations, limitations and challenges involved in the use of these data. However, developing strategies to overcome these limitations (mainly limitations imputable to the PRTR data) as well as improving the PRTR reporting requirements could improve the overall
quality of the data so that it can be better used for research, knowledge translation to the public and future policy applications.
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Disclaimer:

This paper was co-authored by Dr. Stephen C. DeVito, Senior Scientist with the U.S. Environmental Protection Agency. Statements made in this paper do not necessarily represent the views, rules, positions, policies or practices of the U.S. Environmental Protection Agency, nor does mention of any chemical substance constitute an official Agency endorsement or recommendation for use.
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emissions of volatile organic compounds and the incidence of cancer in Indiana counties.


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Evidence from the Toxic Release Inventory in Massachusetts. Review of Economics &


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Economy Initiatives in North America. [online]. Available from
2013].


Choi, H.S., Shim, Y.K., et al. 2006. Potential residential exposure to toxics release inventory
chemicals during pregnancy and childhood brain cancer. Environ Health Perspect
114(7):1113-1118.


EPA 2012c. United State Environmental Protection Agency. [online]. Available from


Jackson, J. 2000. A Citizen’s Guide to the National Pollutant Release Inventory—Community Right to Know: How to Find Out What Toxics are Being Released into Your


Thorning 2009. Community Knowledge and Use of the National Pollutant Inventory. thesis, Griffith University.


<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Title</th>
<th>PRTR Country</th>
<th>PRTR years</th>
<th>Outcome Studied</th>
<th>Population&amp;location</th>
<th>Chemicals</th>
<th>Industry Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>(Mitra and Faruque 2004)</td>
<td>Breast cancer incidence and exposure to environmental chemicals in 82 counties in Mississippi</td>
<td>TRI (US)</td>
<td>Unknown</td>
<td>Breast cancer incidence</td>
<td>Women; Mississippi, U.S. by county</td>
<td>All</td>
<td>All</td>
</tr>
<tr>
<td>2006</td>
<td>(Boeglin, Wessels et al. 2006)</td>
<td>An investigation of the relationship between air emissions of volatile organic compounds and the incidence of cancer in Indiana counties</td>
<td>TRI (US)</td>
<td>1988</td>
<td>Cancer incidence</td>
<td>Whole population; Indiana Counties, U.S.</td>
<td>VOCs</td>
<td>All</td>
</tr>
<tr>
<td>No.</td>
<td>Year</td>
<td>Authors</td>
<td>Title</td>
<td>Database Type (Location)</td>
<td>Time Period</td>
<td>Outcome</td>
<td>Location</td>
<td>Exposure</td>
</tr>
<tr>
<td>-----</td>
<td>------</td>
<td>---------</td>
<td>-------</td>
<td>--------------------------</td>
<td>-------------</td>
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<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>9</td>
<td>2007</td>
<td>(Ho 2007)</td>
<td>Three essays on toxic chemical releases, house values, health and labor productivity</td>
<td>TRI (US)</td>
<td>1987 to 2000</td>
<td>Cancer mortality, house prices</td>
<td>Whole population; U.S. Counties</td>
<td>All</td>
</tr>
<tr>
<td>10</td>
<td>2008</td>
<td>(Dahlgren, Klein et al. 2008)</td>
<td>Cluster of Hodgkin’s lymphoma in residents near a non-operational petroleum refinery</td>
<td>TRI (US)</td>
<td>1990</td>
<td>Hodgkin’s disease</td>
<td>Whole population; Sugar Creek, Missouri, U.S.</td>
<td>Benzene</td>
</tr>
<tr>
<td>11</td>
<td>2008</td>
<td>(Ho and Hite 2008)</td>
<td>The benefit of environmental improvement in the south-eastern United States: Evidence from a simultaneous model of cancer mortality, toxic chemical releases and house values</td>
<td>TRI (US)</td>
<td>1987 to 2000</td>
<td>Cancer mortality</td>
<td>Whole population; South-eastern states, U.S. Counties</td>
<td>All</td>
</tr>
<tr>
<td>12</td>
<td>2008</td>
<td>(Monge-Corella, Garcia-Perez et al. 2008)</td>
<td>Lung cancer mortality in towns near paper, pulp and board industries in Spain: a point source pollution study</td>
<td>EPER (SPA)</td>
<td>2001</td>
<td>Lung cancer mortality</td>
<td>Towns less than 10,000; Spain</td>
<td>Whole</td>
</tr>
<tr>
<td>13</td>
<td>2009</td>
<td>(Garcia-Perez, Pollan et al. 2009)</td>
<td>Mortality due to lung, laryngeal and bladder cancer in towns lying in the vicinity of combustion installations</td>
<td>EPER (SPA)</td>
<td>2001</td>
<td>Lung, larynx and bladder cancer mortality</td>
<td>All towns; Spain</td>
<td>All</td>
</tr>
<tr>
<td>15</td>
<td>2010</td>
<td>(De Roos, Davis et al. 2010)</td>
<td>Residential proximity to industrial facilities and risk of non-Hodgkin lymphoma</td>
<td>TRI (US)</td>
<td>Unknown</td>
<td>Non-Hodgkin lymphoma incidence</td>
<td>Whole population; Facility locations only</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>16</td>
<td>2010</td>
<td>(Garcia-Perez, Lopez-Cima et al. 2010)</td>
<td>Leukemia-related mortality in towns lying in the vicinity of metal production and processing installations</td>
<td>EPER (SPA)</td>
<td>2001</td>
<td>Digestive system cancer mortality</td>
<td>All towns; Spain</td>
<td>All</td>
</tr>
<tr>
<td>17</td>
<td>2010</td>
<td>(Garcia-Perez, Lopez-Cima et al. 2010)</td>
<td>Mortality due to tumours of the digestive system in towns lying in the vicinity of metal production and processing installations</td>
<td>EPER (SPA)</td>
<td>2001</td>
<td>Leukemia-related mortality</td>
<td>All towns; Spain</td>
<td>All</td>
</tr>
<tr>
<td>18</td>
<td>2011</td>
<td>(Conley 2011)</td>
<td>Estimation of exposure to toxic releases using spatial interaction modeling</td>
<td>TRI (US)</td>
<td>1987 to 1996</td>
<td>Lung cancer mortality</td>
<td>Whole population; U.S. Counties</td>
<td>Carcinogens</td>
</tr>
<tr>
<td>19</td>
<td>2011</td>
<td>(Fortunato, Abellan et al.)</td>
<td>Spatio-temporal patterns of bladder cancer incidence in Utah (1973-2004) and their</td>
<td>TRI (US)</td>
<td>1988 to 2004</td>
<td>Bladder cancer incidence</td>
<td>Whole population; Utah, U.S.</td>
<td>Facility locations only</td>
</tr>
</tbody>
</table>
### 20. 2011 (Luo, Hendryx et al. 2011)

**Association between Six Environmental Chemicals and Lung Cancer Incidence in the United States**  
TRI (US)  
1988 to 1990  
Lung cancer incidence  
Whole population; 215 U.S. Counties in 13 states  
arsenic, 1,3 butadiene, cadmium, chromium, formaldehyde, and nickel

### Childhood cancer

| 21. 2005 (Knox 2005) | Oil combustion and childhood cancers  
PI (UK)  
2001  
Childhood cancer incidence  
Children under 16; Great Britain  
1,3-butadiene, benzopyrene, dioxins, benzene, nitrogen oxides, carbon monoxide, non-methane volatile organic substances, and fine particulates

### 22. 2006 (Choi, Shim et al. 2006)

**Potential Residential Exposure to Toxics Release Inventory Chemicals during Pregnancy and Childhood Brain Cancer**  
TRI (US)  
1987 to 1997  
Childhood brain cancer incidence  
Children under 10; Florida, New Jersey, New York (excluding New York City) and Pennsylvania, U.S.  
known, probable and possible carcinogens

### 23. 2007 (Bhat 2007)

**Toxics Release Inventory facilities and childhood cancer: geographic information systems based approach**  
TRI (US)  
1995  
Childhood cancer incidence  
Children under 14; Texas, U.S.  
All; All

### 24. 2008 (Thompson, Carozza et al. 2008)

**Geographic risk modeling of childhood cancer relative to county-level crops, hazardous air pollutants and population density characteristics in Texas**  
TRI (US)  
1990 to 2002  
Childhood cancer incidence  
Children born from 1990 to 2002; Texas Counties, U.S.  
1988 core chemicals  
Petroleum refineries, petroleum refining and related industries, chemical industries and plastics production

### Neuro-development

| 25. 2007 (Suarez, Brender et al. 2007) | Maternal Exposures to Hazardous Waste Sites and Industrial Facilities and Risk of Neural Tube Defects in Offspring  
TRI (US)  
1996 to 2000  
Neural tube defect incidence  
Whole population; Texas, U.S.  
All; All

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http://mc06.manuscriptcentral.com/er-pubs
<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>Authors</th>
<th>Title</th>
<th>TRI (US)</th>
<th>Study Details</th>
<th>Place of Publication</th>
<th>Chemicals/Toxins</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.</td>
<td>2009</td>
<td>Currie and Schmieder 2009</td>
<td>Fetal Exposures to Toxic Releases and Infant Health</td>
<td>1988 to 1999</td>
<td>Gestation, birth weight and infant mortality</td>
<td>Children under 1, U.S Counties</td>
<td>Known developmental toxicants</td>
</tr>
<tr>
<td>27.</td>
<td>2010</td>
<td>Agarwal, Banterghans a et al. 2010</td>
<td>Toxic exposure in America: Estimating fetal and infant health outcomes from 14 years of TRI reporting</td>
<td>1989 to 2002</td>
<td>Infant and fetal mortality rates</td>
<td>Whole population; U.S Counties</td>
<td>Developmental or reproductive toxins</td>
</tr>
<tr>
<td>28.</td>
<td>2004</td>
<td>Yauck, Malloy et al. 2004</td>
<td>Proximity of residence to trichloroethylene-emitting sites and increase risk of offspring congenital heart defects among older women</td>
<td>1996 to 1999</td>
<td>Congenital heart defect</td>
<td>Whole population; Milwaukee, Wisconsin, U.S</td>
<td>trichloroethylene</td>
</tr>
<tr>
<td>29.</td>
<td>2009</td>
<td>Langlois, Brender et al. 2009</td>
<td>Maternal residential proximity to waste sites and industrial facilities and conotruncal heart defects in offspring</td>
<td>1996 to 2000</td>
<td>Congenital cardiovascular malformations</td>
<td>Whole populations; Texas</td>
<td>Facility locations only, all with air emissions</td>
</tr>
<tr>
<td>30.</td>
<td>2006</td>
<td>Palmer, Blanchard et al. 2006</td>
<td>Environmental mercury release, special education rates, and autism disorder: an ecological study of Texas</td>
<td>2001</td>
<td>Autism incidence; Special education rates</td>
<td>Whole population; Texas, U.S. Counties</td>
<td>mercury</td>
</tr>
<tr>
<td>32.</td>
<td>2009</td>
<td>Palmer, Blanchard et al. 2009</td>
<td>Proximity to point sources of environmental mercury release as a predictor of autism prevalence</td>
<td>1998</td>
<td>Autism incidence</td>
<td>Whole population; Texas, U.S. School districts</td>
<td>mercury</td>
</tr>
<tr>
<td>33.</td>
<td>2011</td>
<td>Bartell and Lewandowski 2011</td>
<td>Administrative censoring in ecological analyses of autism and a Bayesian solution</td>
<td>2001</td>
<td>Autism incidence</td>
<td>Whole population; Texas, U.S.</td>
<td>mercury</td>
</tr>
<tr>
<td>34.</td>
<td>1997</td>
<td>Tiefenbacher , Konopka et al. 1997</td>
<td>Airborne toxic emission hazards in Texas: measuring the vulnerability of place</td>
<td>1990</td>
<td>Disease mortality: lung and respiratory cancers, all cancers, lung infections, asthma, emphysema, pulmonary</td>
<td>Whole population; Texas, U.S. Counties</td>
<td>Airborne toxic chemicals</td>
</tr>
<tr>
<td>ID</td>
<td>Year</td>
<td>Authors</td>
<td>Title</td>
<td>TRI (US)</td>
<td>Start Year</td>
<td>Type of Mortality</td>
<td>Study Area</td>
</tr>
<tr>
<td>----</td>
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<td>------------</td>
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</tr>
<tr>
<td>35</td>
<td>2010</td>
<td>Hendryx, Fedorko et al. (2010)</td>
<td>Pollution Sources and Mortality Rates Across Rural-Urban Areas in the United States</td>
<td>TRI (US)</td>
<td>2008</td>
<td>Population mortality</td>
<td>Whole population; U.S. Counties</td>
</tr>
</tbody>
</table>

### Other

<table>
<thead>
<tr>
<th>ID</th>
<th>Year</th>
<th>Authors</th>
<th>Title</th>
<th>TRI (US)</th>
<th>Start Year</th>
<th>Type of Mortality</th>
<th>Study Area</th>
<th>Exposure Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>2001</td>
<td>Meliker, Nriagu et al. (2001)</td>
<td>Spatial clustering of emergency department visits by asthmatic children in an urban area: South-western Detroit, Michigan</td>
<td>TRI (US)</td>
<td>Unknown</td>
<td>Emergency department admissions for asthma</td>
<td>Whole population; South-Western Detroit, Michigan, U.S.</td>
<td>All</td>
</tr>
<tr>
<td>39</td>
<td>2008</td>
<td>Gregory, Shendell et al. (2008)</td>
<td>Multiple Sclerosis disease distribution and potential impact of environmental air pollutants in Georgia</td>
<td>TRI (US)</td>
<td>2002</td>
<td>Multiple sclerosis</td>
<td>Whole population; Georgia, U.S. Counties</td>
<td>Carcinogens and toxicant source emissions</td>
</tr>
<tr>
<td>40</td>
<td>2009</td>
<td>Ho and Hite (2009)</td>
<td>Toxic chemical releases, health effects and productivity losses in the United States</td>
<td>TRI (US)</td>
<td>2002</td>
<td>Self-reported health status</td>
<td>Whole population; U.S. Counties</td>
<td>All</td>
</tr>
</tbody>
</table>
### Table 2: Other uses of PRTR data in identified publications

<table>
<thead>
<tr>
<th>Other uses of PRTR data:</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment of the factors affecting environmental performance</td>
<td>41</td>
</tr>
<tr>
<td>Evaluation of human health risk and possible impact</td>
<td>29</td>
</tr>
<tr>
<td>Presentation of tools, models methods and methodologies for research using PRTR data</td>
<td>25</td>
</tr>
<tr>
<td>Presentation of chemical measurements and characteristics</td>
<td>18</td>
</tr>
<tr>
<td>Evaluation of emission amounts and the accuracy of the data</td>
<td>12</td>
</tr>
<tr>
<td>Analysis of PRTR data along with socio-economic variables to investigate relationships</td>
<td>10</td>
</tr>
<tr>
<td>social justice and demographics</td>
<td></td>
</tr>
<tr>
<td>Examination of trends in chemical releases</td>
<td>6</td>
</tr>
<tr>
<td>Awareness and use of PRTR data by the community</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>144</strong></td>
</tr>
</tbody>
</table>

(a. When studies fit into more than one category, they were classified by the main theme.)
**Table 3:** Classifications of limitations imputable to PRTR data, identified from both health outcomes and other uses of PRTR data publications.

<table>
<thead>
<tr>
<th>Limitations Identified</th>
<th>HO</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of non-threshold emissions reporting</td>
<td>8</td>
<td>36</td>
<td>44</td>
</tr>
<tr>
<td>Change in reporting requirements over time</td>
<td>2</td>
<td>27</td>
<td>29</td>
</tr>
<tr>
<td>Lack of tracking all chemicals in use</td>
<td>4</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td>Lack of mobile and/or other area specific sources</td>
<td>8</td>
<td>16</td>
<td>24</td>
</tr>
<tr>
<td>Under-reporting of emissions</td>
<td>2</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>Incorrect facilities address, including geocoding.</td>
<td>7</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>Data requires expert interpretation</td>
<td></td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Incomparability in reporting requirements among PRTR systems</td>
<td></td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Estimation errors and assumptions in data reporting</td>
<td>4</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Exposure can predate the first reporting year</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Different facilities may report each year as emissions</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>fluctuate within a facility under or above threshold</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>40</td>
<td>163</td>
<td>203</td>
</tr>
</tbody>
</table>

*a. HO= health outcomes, Other = other uses.*
Table 4: Classifications of other limitations using PRTR data, identified from both health outcomes and other uses of PRTR data publications.

<table>
<thead>
<tr>
<th>Other Limitations Identified</th>
<th>HO</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of confounding variables</td>
<td>36</td>
<td>31</td>
<td>67</td>
</tr>
<tr>
<td>Lack of use of toxic potential</td>
<td>10</td>
<td>53</td>
<td>63</td>
</tr>
<tr>
<td>No dispersion modelling to estimate exposure</td>
<td>19</td>
<td>40</td>
<td>59</td>
</tr>
<tr>
<td>Aggregation of population data and exposure</td>
<td>16</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>Modified Areal Unit Problem</td>
<td>5</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Assessment of lag time between exposure and health effects</td>
<td>12</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>98</td>
<td>139</td>
<td>237</td>
</tr>
</tbody>
</table>

a. HO= health outcomes, Other = other uses.
Figure 1: literature selection process
1057x789mm (72 x 72 DPI)
Figure 2: The figure presents the yearly distribution of all identified publications using PRTR according to the focus of the study: health outcomes and other uses. (*Jan-July 2011)

68x37mm (300 x 300 DPI)
Figure 3: The figure displays the total number of included PRTR and health outcomes publications (1993 to 2011) as well the number of yearly publications focusing on children and adults.