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Review

Firewater Storage, Treatment, Recycling and Management: New Perspectives Based on Experiences from the United Kingdom

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Abstract: Smart firewater management and recycling helps reduce water use and protect the environment from pollution. However, contamination of recycled water may pose a health risk to fire fighters. This review assesses international literature to identify best practices, and to recommend new technologies and methods on firewater management and recycling. The literature assessment indicates that this is a new research area where insufficient findings have been published in Web of Science-referenced journals. Therefore, informally published materials (a.k.a. grey literature) were also assessed. Findings indicate the need for practical decision support tools to estimate consumption rates, predict "bottlenecks" and bund capacity, assess water quality and determine pump requirements. This article recommends that cost-efficient and rapid on-site treatment methods, such as compact and mobile filtration units for firewater recycling should be researched in the future. The filters should be based on compartments with different media. The empty pore space should decrease from inflow to outflow. A light plastic media should be positioned near the inflow to retain large particles, such as a grid. Activated carbon media could be placed near the outlet to remove fine suspended solids and dissolved contaminants. This should address concerns by fire fighters dealing with contaminated water, spray and foam.

Keywords: activated carbon; bund system; filtration; fire fighting; foam; pump; run-off; pump; water quality; Web of Knowledge

1. Rationale, Purpose and Scope

1.1. Rationale

Anecdotal evidence indicates that on some fire incident occasions, firewater is collected and recycled by jetting it back onto the fire. There might be real commercial and environmental value to society in better understanding the benefits (or otherwise) and practicalities of firewater recycling for different incident scenarios.

The impact of heated and/or contaminated fire water runoff on the built environment requires a full assessment based on best management guidelines and the wider literature. The focus of the review was on developed countries in temperate and oceanic climates such as the United Kingdom.

The overall advantages of effective firewater management and the recycling of firewater runoff are highlighted in the article. However, general occupational health, environmental and economic disadvantages were also critically assessed. Moreover, the potential to recycle runoff for different scenarios based on simple, transparent and rapid decision support tools needs to be reviewed. A critical assessment of appropriate runoff treatment technologies, methodologies and strategies was performed.

Greater Manchester located in the north-east of England was selected as a case study area to assess different strategies of fire water runoff management. Recommendations for best practice and further studies were made.

1.2. Aim and Objectives

The overall aim of this review is to provide a review of firewater management and recycling. The objectives of the study are to:

- highlight the advantages and disadvantages of firewater recycling, discussing the impacts of firewater runoff on the environment and society;
- discuss firewater quantity estimations, assessing the cost implications of increased firewater and pump use, and new equipment requirements;
- assess firewater recycling options;
- evaluate firewater bund systems and in-drain containment;
- outline the role of firewater pumps, assessing potential damage to equipment due to obstructions caused by the recycled water;
- discuss current practices for a relevant case study;
- identify challenges associated with innovative strategies, (operational) methodologies and (filtration treatment) technologies; and
- provide recommendations based on "best practice" since about 2003.

1.3. Search Terms

The Thomson Reuters Web of Knowledge database [1] was used as a tool to search for scientific references. The relevant time period covered the previous ten years (since 2003). All recognized publication outlets including journals, conferences and books were considered. The number of search term entries per topic is shown in brackets: fire water (78); firewater (23); fire water management (1);

firewater management (0); fire water pump (1); firewater pump (0); fire water recycling (0); firewater recycling (0); fire water runoff (0); firewater runoff (0); fire water run-off (0) and firewater run-off (0). An additional unrestricted search regarding treatment technologies and associated material was performed using Thomson Reuters Web of Knowledge.

Considering that the Web of Knowledge search revealed that firewater recycling is a relatively new research area with few references, Google [2] was used to scan the internet for the same search term entries as shown above. However, no search restrictions including time were set. The search term entries per topic are summarized in brackets: fire water (approximately (approx.) 2,570,000), firewater (approx. 880,000), fire water management (approx. 3,610,000), firewater management (193), fire water pump (approx. 52,100), firewater pump (approx. 10,500), fire water recycling (8), firewater recycling (3), fire water runoff (approx. 743,000), firewater runoff (approx. 900), fire water run-off (approx. 91,900) and firewater run-off (approx. 14,400). Considering the relatively high number of hits, the decision was made to focus only on the terms fire water recycling, firewater recycling and firewater management.

2. Perceived Advantages of Firewater Recycling

Figures 1–4 comprise "real world" examples of firewater runoff pollution, which encourage firewater recycling to save potable water and reduce environmental pollution. Figure 1 shows an example of a local stream polluted by firewater runoff. Examples for industrial estates contaminated by foam-based and water-based firewater runoff are indicated by Figures 2 and 3, respectively. An urban environment flooded by firewater runoff during the night can be seen in Figure 4. The figures illustrate the need for runoff recycling.

Based on anecdotal evidence and grey literature, the benefits of increased recycling of firewater runoff include:

- Reduction of the environmental impact due to reduced contamination reaching storm water drains and watercourses [3,4];
- Less potable water consumed and less associated energy used to clean and pipe it [4];
- Reduced reliance on water utilities for firewater provision and natural water resources;
- Lower exposure to the risk of a water utility cutting off firewater supply;
- Mitigation of the impact of emergency responses to the public;
- Reduction of the risk to fire services to fail to comply with their legal and moral duties to protect the environment, which may otherwise result in financial penalties and/or damage to organizational reputation;
- Fire services can demonstrate that they have taken all reasonable steps to minimize the extent of the (polluting) discharge;
- Reduction of the impacts such as pressure drops on other consumers using the same freshwater source;
- Reduction of the design and/or rehabilitation cost of pipe systems and associated tanks, because less capacity is required.

Figure 1. Example of a local stream, near Calderbrook Road in Littleborough, polluted by firewater runoff (photograph taken by Ian Duckworth).

Figure 2. Example of an industrial estate polluted by foam-based firewater runoff during the day (photograph provided by Ian Duckworth).

Figure 3. Example of an industrial estate polluted by water-based firewater runoff during the day (photograph provided by Ian Duckworth).

Figure 4. Example of an urban environment polluted by firewater runoff during the night (photograph provided by Ian Duckworth).

Learned journals, however, do not cover the above perceived advantages of firewater recycling. Therefore, an assessment of the grey literature was required. Findings of these additional sources indicate that firewater that is heavily contaminated with, for example, foam solution (e.g., Figure 2) requires treatment before it can be recycled. Firewater recycling seems to be an option that is routinely only considered for training practices [5,6].

3. Firewater Management

3.1. Firewater Quantity Estimations

The use of freshwater (particularly potable water) is costly for society, which usually pays indirectly via taxes for the water used when fire services fight fires. Major fires may require several millions liter of water. For example, a fire at Allied Colloids (Bradford, UK) in 1992 consumed about 16 million liter of water [7]. Depending on the charging regime for drinking water supply, the water bill can easily reach several hundred thousand pounds. Firewater quantity estimations are therefore required to keep costs and harm to the receiving environment down [8].

The amount of firewater to be discharged into any drainage system or holding basin is complex to evaluate, because the modeling and standardization of the effective duration of a fire and the related consumption of water required to extinguish the fire depends on multiple variables [8]. Appropriate assumptions on the amount of flammable and/or combustible materials need to be made. Furthermore, burning rates, evaporation effects, available fire fighting systems and process isolation devices have also to be considered.

The estimation of a fire scenario duration leads to the evaluation of the amount of actual consumed firewater [8]. The results may be used to estimate the dimensions of a waste firewater drainage system and capacity wastewater basins holding firewater.

The performance requirements for a firewater recycling system in terms of water flow rates are difficult to estimate, and depend on factors such as how many water supply sources are used and for how long. The rate at which firewater might need to be treated is not necessarily a function of its runoff rate, considering that runoff is usually captured in holding basins for subsequent treatment at a later stage (*i.e.*, days or weeks after the fire has been extinguished). It follows that the choice of firewater treatment system is independent from the actual flow rates during an incident.

In cases where firewater recycling during an incident is possible and advantageous, knowledge regarding the actual firewater demand per fire engine is required. A typical fire engine might require between approximately 1500 and 5000 L of water per minute. If, for example, a modest quantity of 10% of firewater should be recycled during an incident, a corresponding firewater treatment system would be associated with a design flow rate of at least 25 L/s.

3.2. Firewater Recycling

The incidents leading up to a storage tank fire were assessed in a case study [9]. Firewater management issues were also considered. However, they are of little direct relevance to the topic of firewater recycling during and after a fire. Nevertheless, the researchers [9] came to the relevant conclusion that firewater distribution systems should be full-flow performance tested. Any system "bottlenecks" in terms of water supply have to be addressed, and new supply curves should consequently be developed. These curves should be compared to the anticipated fire demand.

Some fire training facilities use retention basins to hold discharged firewater and foam solutions in order to recycle firewater [5]. The firewater is re-used for training purposes. However, the continued addition of foam solution will eventually render the fluids to be useless for producing foam. When this point in time has been reached, the usual practice is to drain or pump the fluids to a private or public sewer without foam and water separation. Fire training facilities do usually not have the capacity to treat the recovered fluids from live fire fighting exercises by removal or treatment of the foam concentrate and the surfactants [5]. This is not necessarily the case due to technical difficulties and/or high costs but due to a lack of environmental awareness and no legislative requirements for treatment [4].

Firewater recycling is considered both in wet countries such as the UK [4] and dry countries such as Australia [6], where water is even more expensive due to droughts. Firewater treatment and recirculation for Australian fire fighting training grounds to achieve fit-for-purpose water quality has been recommended [6]. Options with and without recirculation of firewater are being developed for upgrading and refurbishing the firewater supply system with a view to eliminate contaminants to the greatest extent practicable and to address risk-based criterions such as limiting negative effects on the natural environment and health of fire fighters.

The UK Environment Agency [10] requires the preparation of tertiary containment plans for establishments storing or using liquid dangerous substances. Moreover, the same is the case for sites that may have firewater containing dangerous substances. For larger establishments, on-site effluent facilities that are sized to allow for the collection and subsequent treatment of polluted firewater are a viable option where justifiable according to the Health and Safety Executive [11]. However, no direct reference is made to any particular treatment technology that might be suitable.

The Irish Environmental Protection Agency [12] does not generally recommend the use of firewater retention ponds as a firewater source for further application on a fire. The main reason for this recommendation is the lack of information on contaminants within the collected firewater runoff, indicating the need for a literature review and more research. Information on the entrained products such as the reactivity with water, corrosivity and toxicity should be available before recycling. Exceptions might be allowed for fire emergency situation on a case-by-case basis.

Theoretically, it should be possible to treat typical firewater runoff with various wastewater and storm water technologies. However, the systematic literature search did not reveal the actual application of standard wastewater treatment technologies such as sedimentation tanks, biological filtration and activated sludge process for firewater recycling. It is beyond the scope of this paper to speculate about possible treatment options is detail.

3.3. Bund Systems

The overuse of firewater can carry environmental contaminants such as petroleum products [13] outside bunded areas either directly to the environment (any watercourses and groundwater) or through potentially overloaded wastewater treatment plants indirectly to the environment (mainly rivers and sea) [7]. Therefore, the Health and Safety Executive [11] and the Department for Communities and Local Government [4] indicate that the first principle is to contain firewater run-off on site, for example, with the help of bunds. Where this is not possible or unreasonable, contact should be made with the Environment Agency to identify the best option for minimizing the environmental impact. If firewater run-off has already entered the foul sewage network, the sewage operator (usually the water utility company) must be informed so that they can assess the risk to the treatment process associated with the wastewater treatment plant down-stream of the incident.

The performance of a tank bund system that had a significant impact on fire fighting operations and the extent of the associated pollution has been discussed as part of a case study [14]. Some bunds remained intact but others suffered loss of containment during the fire, releasing firewater containing perfluorooctane sulphonates used in the fire fighting foam. The subsequent pollution of groundwater exceeded the relevant contamination threshold. As a consequence, the competent authority adopted a containment policy to raise standards across the fuel storage sector [14,15].

The Buncefield Standards Task Group [16] has made many recommendations on firewater management and control measures. The group proposed that site-specific planning of firewater management and control measures should be undertaken with active participation of the local fire and rescue services. Consideration should be given to bund design factors including firewater removal pipe work, and aqueous layer controlled overflow to remote secondary or tertiary containment, particularly for immiscible flammable hydrocarbons. Furthermore, the Buncefield Standards Task Group [16] recommended that services should consider firewater and/or foam additive application rates and firewater flows and volumes at worst-case but still credible fire scenarios. Finally, controlled burn options appraisals taking into account planning and media implications would also be beneficial to reduce the impact of firewater runoff to the environment, which has also been recognized by the Health and Safety Executive (2009) [11].

The Health and Safety Executive [11] highlights that site-specific planning of firewater management and control measures should consider bund design factors such as firewater removal pipe work, aqueous layer controlled overflow to remote secondary or tertiary containment (for immiscible flammable hydrocarbons). The executive recommends the control of foam additive application rates, and firewater flows and volumes.

As part of their containment policy, the Environment Agency [10] requires bunds for above-ground storage tanks to have sufficient capacity to allow for tank failure and firewater management. This will normally be a minimum capacity of either 110% of the capacity of the largest tank or 25% of the total capacity of all the tanks within the bund, whichever is the greater. However, it is unclear what is meant by “capacity” according to the Health and Safety Executive [11]. It follows that the actual sizing of bunds will have to be determined by the estimated hazards and associated risks, which are difficult to estimate in practice. Bund size has an obvious implication on the volume and potential contamination of firewater that could be recycled.

Adequate pipe provision for firewater transfer should be provided. Firewater and foam additive application rates and firewater flows and volumes at worst-case credible scenarios should be provided by the plant operator. Recycling of firewater is specifically encouraged by the Environment Agency [10] on occasions where the firewater is not hazardous.

3.4. Firewater In-Drain Containment

The containment of firewater is recommended for environmental reasons in many developed countries [3,4,12]. A presentation on environmental innovations relevant for firewater containment has been compiled previously [17]. Table 1 provides a corresponding overview of commercially available firewater in-drain spill and pollution containment system examples. Products such as Flapstopper and similar technology provide the latest efficient state-of-the-art technology.

Table 1. Overview of commercially available firewater in-drain spill and pollution containment system examples (after [17]).

Characteristics	Drainstopper	Flapstopper	Telestopper
Water-based firewater	Suitable	Suitable	Suitable with personal protective equipment
Oil-contaminated firewater	Suitable	Suitable	Suitable
Chemical spill-contaminated firewater	Suitable	Suitable	Suitable with personal protective equipment
Bio-hazard contaminated firewater	Suitable	Suitable	Suitable with personal protective equipment
Fully automatic system	Yes	Yes	No
Battery-powered system	Yes	Yes	Not applicable
Retrofitting option	Yes	Yes	Not applicable
Re-usability	Yes	Unlimited	Yes
Drain opening (cm) range	10 to 150	10 to 150	Up to 100
Rodent-proof	Protection required	Fully	Yes
Special features	Simple to install from above-ground; easy to maintain; occupies <10% of drain area	Low energy consumption; fully rodent-proof; manual emergency override	Fully portable with 3 m long extension pole; manual or electric pump to inflate

3.5. Firewater Pumps

Effective firewater pump management is essential to control firewater run-off. Hoses and pumps are necessary to transfer firewater run-off from the bund to another bund or catchment area. Alternatives may include purpose-built bund overflows to a remote tertiary containment system or increasing the capacity of an existing bund. Transfer of firewater could be achieved by pumps or via gravity flow [11]. The excessive use of pumps, however, may lead to pump failure due to the degradation of mechanical parts.

Models describing the degradation of mechanical equipment have been discussed previously [18]. They developed their own model and applied it for the analysis of a firewater pump. However, their paper does not focus on firewater recycling issues.

4. Case Study: Greater Manchester Fire and Rescue Services

4.1. Summary of Current Practices

The current practices associated with firewater management undertaken by the Greater Manchester Fire and Rescue Services are representative for those of larger fire services in the UK, considering that they are following national standards [4]. However, the need for innovation is driven by a cost savings agenda in the North-west of England, which is a relatively poor region compared to the South-east of the country. Greater Manchester Fire and Rescue Services [19] have their own Environmental Protection Strategy. The author visited Bury Fire Station (established in 2013), which is part of the Greater Manchester Fire and Rescue Services on 3 November 2013. This is the only fire station within Greater Manchester that is equipped with specific water and environmental protection equipment and consumables, which are only used for large industrial-scale fires (e.g., Figures 2 and 3) if and when appropriate. The dedicated kit is currently confined to two mobile storage units, which have the size of a shipping container. However, one unit is on loan from another English fire and rescue service.

The environmental protection kit comprises equipment designed to store temporarily small, medium and large quantities of firewater. The small and medium holding devices are only permanently open to the environment at the top where water can be stored and recycled if and when required. In contrast, the large holding devices comprise bunds, which are permanently open at the top and bottom. The permeability of the bottom is a function of the semi-natural ground condition; e.g., an asphalted street (e.g., Figure 4) and car park surface is relatively impermeable while a compacted earth surface area may be leaky depending on soil type and saturation.

Contaminated firewater and associated sediments and sludges held within the temporary storage devices are routinely handed-over to the Environment Agency at the end of a fire incident. The Environment Agency treats the liquids and solids as potentially hazardous wastes, and arranges for treatment and/or disposal via licensed waste contractors. It follows that only the handling of the firewater itself and not the sediment is within the remit of responsibility of the fire service. However, sediment at the bottom of a holding devise may be sucked into a pump if the pump inlet is coming too close to the bottom of the holding device, which is possible during real fire incidents.

The fire service uses also mechanical and semi-hydraulic equipment to block-off gully pot openings and small drains to prevent firewater escaping into the built or natural environment. However, for blocking of large drains and sewers, the environment unit depends on large-scale equipment provided by United Utilities (regional water and wastewater company).

The protection kit is supplemented by consumables such as specific clothes designed to either soak-up water or hydrocarbons. These consumables will be handed-over to the Environment Agency after use for disposal as well.

For approximately 10% of fire appliances, the service has a telemetry-enabled metering system, which provides real time information to pump operators allowing them to monitor pressures and volumes coming into the tank from the water sources such as hydrants and control the firewater being pumped onto the fire. These data together with locations are logged and hosted externally.

4.2. Identified Challenges and Solution Proposals

The greatest challenges that the regional fire service faces are around cultural change associated with environmental awareness of some fire fighters, health and safety concerns when recycling contaminated firewater and technical issues such as blockage of pumps and nozzles. Decision-support charts when dealing with firewater and foam (minority of cases) recycling could be introduced to the handbook of each fire engine. The charts would propose solutions to a challenge based on a decision matrix or, where appropriate, a decision tree. The decision support tool could be based on a database of previous experiences documented in incident log books. This measure could be supplemented by dedicated training sessions. This recommendation complements well previous proposals made by the fire service [19].

The opportunity to recycle firewater should be balanced by consideration of alternative options to achieve the same aim. For major fire incidents and if economically reasonable, firewater should be pre-treated before recycling with the support of (mobile, if feasible) filtration units [20], which would address the proposal by the Department for Communities and Local Government [4] to promote the recycling of firewater that is not hazardous. This could minimize heath issues associated with contaminants coming into contact with the skin and/or entering the nose, mouth and eyes of fire fighters and the by-standing public during real fire incidents. A much simpler filtering unit based on sieving (e.g., rotating microsieves) and straining technology [20–22] could be used to prevent large particles blocking pumps. However, these filtration units have to be relatively small due to space restrictions in the container unit. Alternatively, a false bottom within the temporary firewater holding tanks could separate large solids from the firewater by gravity, reducing the risk of them being sucked into pumps where they could cause blockages.

In cases when overflow of firewater heavily contaminated by solids and grit into sewer systems is unavoidable, the rapid cleaning of potentially full silt traps [23] in coordination with the sewer system operator (United Utilities) and the Environment Agency is a preventive measure that protects the environment from avoidable contamination. However, a corresponding cultural change would be required within the fire service, which is naturally more focused on fighting fires than protecting the environment. Nevertheless, silt trap management could be integrated within the proposed decision support tool covering aspects such as management and technological solutions to different problem scenarios; e.g., coordination between different stakeholders and evaluation of available equipment.

Temporary storage and clean-up of relatively small quantities of firewater in storm water detention systems [24] and nearby ditches [25,26] should be explored. Moreover, long-term recycling of firewater could be achieved with the support of compact vertical-flow wetland systems [20,27]. Filters that require long-term clean-up operation of runoff may be planted with robust *Phragmites australis* [28]. The removal of contaminants such as hydrocarbons could be achieved by using cheap recycled agricultural waste products such as corn stalk, saw dust and straw, which have shown remarkable performance in adsorbing and absorbing oil spills in previous studies [29–31].

A filter with multi-purpose use such as protecting pumps, the health of fire fighters and the natural environment could also be tested. The filter should be based on flexible compartments with different media. The empty pore space between media should decrease from the inflow to the outflow of the filtration system. Light plastic media [32] should be packed near to the inflow of the filter to retain large particles such as grid and stones that may block pumps. Natural coagulation and disinfection media such as *Moringa oleifera* [33] could be suitable for the centre of the filter. Activated carbon [34] media should be placed near the outlet to remove fine suspended solids and dissolved contaminants such as those associated with foam products.

5. Conclusions and Recommendations

The review highlighted the lack of published information on firewater management and recycling. Findings based on Web of Science-referenced literature indicates that firewater consumption rates should be calculated using predictive models taking the recycling option into account. The firewater distribution systems must be full-flow performance tested in order to identify potential "bottlenecks" such as weak pumps and small diameter pipes accurately. Potentially contaminated firewater should be contained within small flexible and large ground-bound bunds, and key water quality parameters must be assessed before release to the environment or sewer system. Firewater pump damage and blockages should preferably be predicted with mechanical degradation models to avoid "bottlenecks" in firewater supply when multiple pumps become rapidly clogged.

The lack of scientific literature on firewater recycling necessitated an additional unrestricted search using Google. A study of the grey literature indicated that firewater heavily contaminated by, for example, foam solution and hydrocarbons cannot be effectively recycled and require disposal or treatment. The main barrier for recycling of firewater in general is the fear of unknown health effects associated with contaminants on fire fighters.

The Greater Manchester Fire and Rescue Services case study indicated the need for training of fire fighters in the use of simple decision support tools to decide if, and for how long, firewater should be recycled. Technical issues such as blockage of pumps and nozzles can easily be addressed by the introduction of fine sieves. Health and safety concerns when recycling heavily contaminated firewater should be addressed by compact, light and mobile filtering technology.

The author recommends that applied research on the rapid on-site treatment and storage options of recycled firewater and foam should be conducted. Mobile filtration units capturing large particles with light plastic media and dissolved contaminants with activated carbon should be researched. Considering that firewater flow rates are likely to be high, more research on the hydraulic performances including design flow rates and empty bed contact times of treatment systems should also be undertaken. Corresponding outcomes need be taken into account when designing decision-support charts on firewater recycling. This investment should lead to the reduction of water bills and the protection of fire fighters, bystanders, wastewater treatment plants and the environment.

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Conflicts of Interest

The author declares no conflict of interest apart from receiving part-funding by the Greater Manchester Fire and Rescue Service.

References

1. Web of Knowledge. Thomson Reuters Web of Knowledge Home Page. Available online: http://wok.mimas.ac.uk (accessed on 30 October 2013).
2. Google Home Page. Available online: http://www.google.co.uk (accessed on 30 October 2013).
3. Department of Environment and Conservation. *Environmental Compliance Report: Liquid Chemical Storage, Handling and Spill Management (Part A: Compliance Audit)*; Department of Environment and Conservation: New South Wales, Sydney, Australia, 1995. Available online: http://www.environment.nsw.gov.au/resources/licensing/ecrchemicalsa05589.pdf (accessed on 11 November 2013).

4. Department for Communities and Local Government (DCLG). *Environment Handbook for the Fire and Rescue Service. National Operational Guidance Programme Consultation Document*; DCLG and the Environment Agency: London, UK, 2013.
5. Risk and Policy Analysts (RPA). *Risk Reduction Strategy and Analysis of Advantages and Drawbacks for Perfluorooctane Sulphonate (PFOS)*; Final Report Prepared by RPA for the Department for Environment, Food and Rural Affairs and the Environment Agency for England and Wales in association with the British Research Establishment Environment: Norfolk, England, UK, 2004. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/183154/pfos-riskstrategy.pdf (accessed on 31 October 2013).
6. Country Fire Authority (CFA). *Response to the Professor Joy Report of the independent investigation into the CFA Facility at Fiskville*; CFA: Burwood East, Victoria, Australia. Available online: http://www.cfa.vic.gov.au/fm_files/attachments/Publications/fiskville-investigation/cfa-response/CFA-response-to-Professor-Joy-report.pdf (accessed on 12 November 2013).
7. Vince, I. *Major Accidents to the Environment—A Practical Guide to the Seveso II-Directive and COMAH Regulations*; Butterworth-Heinemann, Elsevier: Oxford, UK, 2008.
8. Rigolio, M. Fire Fighting in Process Plants: Analysis of Actual Firewater Consumption. In Proceedings of the CISAP4, 4th International Conference on Safety and Environment in Process Industry, Florence, Italy, 14–17 March 2010.
9. Rodante, T.V. Investigation of a naphtha storage tank fire. *Process Saf. Progress* **2005**, *24*, 98–107.
10. Environment Agency. *Containment of Bulk Hazardous Liquids at COMAH Establishments—Containment Policy Supporting Guidance for Secondary and Tertiary Containment*. Environment Agency, Health and Safety Executive and Scottish Environment Protection Agency: London and Stirling, UK, 2008. Available online: http://www.environment-agency.gov.uk/static/documents/Business/release_2041305.pdf (accessed on 2 November 2013).
11. Heath and Safety Executive (HSE). *Safety and Environmental Standards for Fuel Storage Sites*; Final Report; Process Safety Leadership Group, HSE: London, UK, 2009. Available online: http://www.hse.gov.uk/comah/buncefield/fuel-storage-sites.pdf (accessed on 12 November 2013).
12. Environmental Protection Agency. *Fire-water Retention Facilities: (Draft) Guidance Note to Industry on the Requirements for Fire-water Retention Facilities*; Environmental Protection Agency: Wexford, Ireland. Available online: https://www.epa.ie/pubs/advice/licensee/Draft%20firewater%20retention.pdf (accessed on 10 November 2013).
13. Eke, P.E.; Scholz, M. Benzene removal with vertical-flow constructed treatment wetlands. *J. Chem. Technol. Biotechnol.* **2008**, *83*, 55–63.
14. Whitfield, A.; Nicholas, M. Bunding at Buncefield: Successes, Failures and Lessons Learned. Hazards XX: Process Safety and Environmental Protection: Harnessing Knowledge—Challenging Complacency. In *Institution of Chemical Engineers Symposium Series*; Institution of Chemical Engineers: Rugby, UK, 2008.
15. Buncefield firewater clean-up under way. *Professional Engineering*, 13 December 2006; p.12.
16. Rivers, K. Safety and Environmental Standards for Fuel Storage Sites. Available online: http://www.hse.gov.uk/comah/buncefield/bstgfinalreport.pdf (accessed on 11 November 2011).

17. Back, B.M. Environmental Innovations: An Introduction. Available online: http://www.warwickshire.gov.uk/Web/corporate/wccweb.nsf/Pages%20by%20Level%201/472F87E197AA387F802578420 0327F70/$file/EnvironmentalInnovationsCustomerPresentation.pdf (accessed on 10 November 2013).
18. Ramirez, P.A.P.; Johnsen, R.; Utne, I.B. Probabilistic Condition Assessment of Aging Equipment Considering the Effect of Operating Conditions and Maintenance. In Proceedings of the 31st American Society of Mechanical Engineers International Conference on Ocean, Offshore and Arctic Engineering, Rio de Janeiro, Brazil, 1–6 July 2012; Volume 2, pp. 535–545.
19. Greater Manchester Fire and Rescue Services (GMFRS). *Environmental Protection Strategy*; GMFRS: Salford, UK, 2009.
20. Scholz, M. *Wetland Systems to Control Urban Runoff*; Elsevier: Amsterdam, the Netherlands, 2006.
21. Bergheim, A.; Sanni, S.; Indrevik, G.; Holland, P. Sludge removal from salmonid tank effluent using rotating microsieves. *Aquac. Eng.* **1993**, *12*, 97–109.
22. Cheremisinoff, N.P. *Handbook of Water and Wastewater Treatment Technologies*; Elsevier: Amsterdam, the Netherlands, 2001.
23. Scholz, M.; Zettel, S. Stormwater quality associated with a full silt trap discharging into an urban watercourse. *Water Environ. J.* **2004**, *18*, 226–229.
24. Nanbakhsh, H.; Kazemi-Yazdi, S.; Scholz, M. Design comparison of experimental storm water detention systems treating concentrated road runoff. *Sci. Total Environ.* **2007**, *380*, 220–228.
25. Scholz, M.; Trepel, M. Water quality characteristics of vegetated groundwater-fed ditches in a riparian peatland. *Sci. Total Environ.* **2004**, *332*, 109–122.
26. Hedmark, Å.; Scholz, M. Review of environmental effects and treatment of runoff from storage and handling of wood. *Bioresourc.Technol.***2008**, *99*, 5997–6009.
27. Scholz, M. *Wetland Systems—Storm Water Management Control*; Springer Verlag: Berlin, Germany, 2010.
28. Lee, B.-H.; Scholz, M. What is the role of *Phragmites australis* in experimental constructed wetland filters treating urban runoff? *Ecol. Eng.* **2007**, *29*, 87–95.
29. Li, M.M.; Pan, H.-C.; Huang, S.-L.; Scholz, M. Controlled experimental study on removing diesel oil spillages using agricultural waste products. *Chem. Eng. Technol.* **2013**, *36*, 673–680.
30. Annunciado, T.R.; Sydenstricher, T.H.D.; Amico, S.C. Experimental investigation of various vegetable fibers adsorbent materials for oil spills. *Mar. Pollut. Bull.* **2005**, *50*, 1340–1346.
31. Hussein, M.; Amer, A.A.; El-Maghraby, A.; Taha, N.A. Availability of barley straw application on oil spill clean-up. *J. Environ. Sci. Technol.* **2009**, *6*, 123–130.
32. Tang, X.; Huang, S.; Scholz, M.; Li, J. Nutrient removal in vertical subsurface flow constructed wetlands treating eutrophic river water. *Int. J. Environ. Anal. Chem.* **2011**, *91*, 727–739.
33. Ahmed, T.; Kanwal, R.; Hassan, M.; Ayub, N.; Scholz, M. Coagulation and disinfection in water treatment using *Moringa*. *Proc. Inst. Civil Eng. Water Manag.* **2010**, *163*, 381–388.
34. Scholz, M.; Martin, R.J. Ecological equilibrium on biological activated carbon. *Water Res.* **1997**, *31*, 2959–2968.