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Land use, water management and future flood risk☆

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ABSTRACT

Human activities have profoundly changed the land on which we live. In particular, land use and land management change affect the hydrology that determines flood hazard, water resources (for human and environmental needs) and the transport and dilution of pollutants. It is increasingly recognised that the management of land and water are inextricably linked (e.g. Defra, 2004). "Historical context, state of the science and current management issues" section of this paper addresses the science underlying those linkages, for both rural and urban areas. In "Historical context, state of the science and current management issues" section we discuss future drivers for change and their management implications. Detailed analyses are available for flood risk, from the Foresight Future Flooding project (Evans et al., 2004a,b) and other recent studies, and so we use flooding as an exemplar, with a more limited treatment of water resource and water quality aspects. Finally in "Science needs and developments" section we discuss science needs and likely progress. This paper does not address the important topic of water demand except for some reference to the Environment Agency's Water Resources Strategy for England and Wales (Environment Agency, 2009).

Historical context, state of the science and current management issues

The urban environment

Urban development provides a useful illustration of some of the most obvious effects of land use change on water management. Vegetated soils are replaced with impermeable surfaces, increasing overland flow and reducing infiltration, bypassing the natural storage and attenuation of the subsurface. In addition, the conveyance of runoff to streams is modified. Overland runoff is conventionally collected by piped storm-water drainage systems and conveyed rapidly to the nearest stream. The result is a greater volume of runoff, discharging in a shorter time, potentially leading to dramatically increased flood peaks, but also reduced low flows and less groundwater recharge.

Urbanisation effects on fluvial floods

The size of the effect of urban development on streamflow will depend on the natural response of the catchment. The effects will be greatest where natural runoff is low, in catchments with permeable soils and geology, and can include changes in flood seasonality. Natural catchments in the UK mainly flood after prolonged rainfall in winter, when soils are already wet and storm runoff is readily generated. Urban catchments are not so seriously affected by these antecedent conditions and respond more rapidly to rainfall. This means that intense summer rainfall may become a major cause of flooding (Institute of Hydrology, 1999).

It is expected that the relative effects of urbanisation will reduce in larger, rarer floods, but current design guidance to quantify this is highly speculative.

For larger catchments, the effects are more complex, as the location of development within the catchment will affect its response. For example, urban development located near to the outlet of a catchment may generate runoff before the main response of the natural catchment arrives. The overall effect of urbanisation on the catchment flood peak will depend on the relative magnitude and timing of the constituent responses.

These effects have been well known for some 40 years (see e.g. Hall, 1984), and to mitigate them, engineered solutions have routinely been adopted to reduce flood peaks through the provision of storage. One common solution is the construction of a reservoir to provide "detention storage." Crooks et al. (2000) report on the effects of 30 years of urbanisation on two sub-catchments of the Thames, showing an apparent increase in flood frequency with urbanisation, followed by a reduction as storage solutions were implemented.

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There is much interest in Sustainable Urban Drainage Systems (SUDS) to manage urban runoff and associated problems of water quality. Various design solutions can be implemented, for example restoring the infiltration of rainfall into the soil by directing storm runoff to engineered soakaways, or seeking to retard flows within the storm sewer system (Verworn, 2002). However, a lack of clear responsibilities for design and maintenance have limited uptake of SUDS in England and Wales. The official review of the UK's 2007 summer floods (Pitt, 2008) highlights the current problems of governance of water in the urban environment. Pitt also comments on the increasing density of urbanisation. He proposes solutions such as planning controls on paved areas within areas of domestic housing.

While well-developed design guidelines are available for conventional storage, based on a substantial body of research (Hall et al., 1993), the research base to support SUDS applications is much more limited. There is no clear understanding of the effects of extreme rainfall on the performance of SUDS, and there is substantial anecdotal evidence that control of local-scale installations is ineffective, leading to errors in construction and defective operation (Packman, pers. comm.).

Urban stormwater flooding

"Urbanisation effects on fluvial floods" section above addressed the effects of urban development on river flooding. There are also major issues of flooding due to surface runoff within the urban environment. This type of flooding is a major cause of insurance claims for flood damage. Storm runoff is normally channelled via gully pots, into storm sewers, which are usually designed to accommodate relatively frequent events. Under more extreme conditions, these sewers will start to surcharge (flow full under pressure), and as pressures build up, manhole covers can lift and the sewers discharge to the surface. Such flows combine with surface runoff to generate flooding of roads and properties. Urban flooding is often complex. Sewer flooding can arise when pipes exceed their capacity, become blocked, have their capacity limited by river flooding, or a combination of these factors. Divided management responsibilities are a problem in this area. One of the recommendations of the Pitt report (2008) is for clear overall responsibility for urban flooding in England and Wales.

There are technical problems in urban flood design. The frequency of surface flooding for storm sewers is not a design criterion, is often not known, and will vary greatly for different systems. There has been a lack of technical capability to address this problem. But in the past few years, models have been developed to represent the surface routing of overland flows, and associated storm sewer interactions, supported by high resolution topographic data, for example from LIDAR airborne remote sensing systems (Djordjević et al., 2004). This offers exciting potential for a paradigm shift in the design of the urban environment to manage flood risk.

Floodplain development

Finally in this discussion of urban flooding, we turn to issues of development on floodplains. Many major towns and cities are adjacent to rivers, and there are continuing economic pressures to build in river floodplains. However, floodplains have precisely the function that their name suggests; rivers can be expected naturally to flow beyond their banks every few years. The natural functioning of a floodplain is to store and subsequently release flood waters, attenuating a flood as it travels downstream. Over the past century or more, floodplains have been increasingly used for urban and agricultural development, and the need to protect that development has led to engineered disconnection of the river from its floodplain. The result is a loss of flood attenuation, and increases in flood risk downstream. This remains an issue of concern for the major European rivers such as the Rhine. Levels of flood protection for some German cities have significantly decreased and active efforts have been made in recent years to recreate floodplain storage. The same issues arise in the UK, although little work is available to quantify the effects of historic changes. There is now interest in the UK in the potential for the return of floodplain land to an active water storage role, for example by reducing the level of flood protection of agricultural floodplain land (see below).

Recent moves have been made by the UK Government to strengthen the role of the Environment Agency in the planning process in England and Wales (CLG, 2006), and also to raise awareness of planners of the risks of flooding. A particular problem, highlighted by the 2007 floods, is the location of strategically important utility infrastructure in floodplains. It is also not uncommon for emergency services, hospitals and residential homes for the elderly to be located in floodplains.

Water resource and water quality tissues

Towns and cities need water supplies, which are often imported from other catchment areas. After use, this water is conventionally routed through the sewer system, treated, and discharged to the local river. Urbanisation reduces natural water infiltration into soil, so that in urban rivers, effluent discharge may be a dominant component of river flows, particularly under the low flow conditions of summer.

The release of treated effluents to streams has long been a major source of pollution, and nutrients have been a particular concern. EU legislation, in the form of the Urban Wastewater Treatment Directive, has required major treatment works to introduce tertiary treatment to reduce nutrient loads, but this requirement does not extend to the large numbers of small treatment facilities. Jarvie et al. (2007) report observations of phosphorus in the river Lambourn in Berkshire. These measurements show the effect of sewage effluent on phosphorus loads in the river, the reduction in phosphorus when treatment was improved, and the subsequent release of phosphorus from river sediments as the system re-equilibriated.

In addition to the discharge of treated effluents, there is potential for pollution from urban storm runoff, which can include oils and heavy metals. Urban storm drainage systems normally include simple devices, such as gully pots, to collect sediments and associated pollutants, while one of the roles of SUDS, discussed above, is to reduce pollutant discharge. Particular problems arise where storm and foul sewers are combined. Under extreme flows, treatment facilities are unable to accept the storm discharges, and overflows of sewage effluent to watercourses can occur. This is a concern for pollution of the Thames in London, and is one of the motivations for major investment in a new interceptor sewer.

There is also scope in urban areas for a wide range of pollutants to be released to the water environment from accidents, spillages, broken pipes and illegal activities. In recent years, industrial pollution of surface water systems in the UK has been greatly reduced in response to tighter regulatory controls. But in the subsurface, there is a legacy of pollution of soils and groundwater, with long-term consequences. Groundwater in urban environments is commonly polluted and is not suitable as a potable resource.

The management of water in the urban environment can significantly modify hydrological impacts. The harvesting of rainwater from roofs can reduce both storm runoff and the demand for other water resources, while the re-use of so-called 'grey water' at a domestic scale is technically feasible, although not currently economic (Liu et al., 2007). Vegetation can be used to attenuate and reduce runoff and associated pollution, either at the scale of 'Green Roofs' or in larger scale implementation of SUDS. In water-limited areas, the management of urban water has been intensified, and