Mk84 bomb can damage a water reservoir, warehouse for spare parts, and a water supply operator within its target area of hundreds of metres, simultaneously.

As shown in Table 2, the extent of the reverberating effects of explosive weapons on urban services changes in space and time with the pre-attack baseline resilience of the service. To recall – for a service that is quite resilient prior to an attack, the reverberating effects of explosive weapons are expected to be dampened because the redundancies can provide alternative supply options and/or routes, and the spare parts and people required to install them are still available. By contrast, the reverberating effects of explosive weapons on a service that is quite vulnerable – that is to say, one that is already 'on its knees' – can extend much further afield and forward in time.

Investigating the determinants of the impact of the reverberating effects of explosive weapons on urban services thus obliges tackling several sets of variables: the three components of each service; the interdependencies of services; direct effects; reverberating effects; and the up, mid, and downstream hierarchy. Table 2 clarifies the dynamics through a systematic summing of alternatives of the different sets of variables in different scenarios. The summary reveals the extent to which the baseline conditions and hierarchy influence the expected impact of the explosive weapons in space and time.

Baseline Resilience		Hierarchy	Reverberating Effects		
Redundancies	Preparedness/ capacity to Respond	Hierarchy of explosion (in the service)	Impression in <u>space</u> Confined or Open	Impression in <u>time</u> 1 = Immediate 2 = Short-term 3 = Mid-term 4 = Long-term	Magnitude (relative number of people affected) Low, Med, High
High	High	Downstream	Confined	1	L
High	High	Midstream	Confined	2	M
High	**High**	**Upstream**	**Open**	**2**	**H**
High	Med	Downstream	Confined	3	L
High	Med	Midstream	Confined	3	M
High	**Med**	**Upstream**	**Open**	**3**	**H**
High	Low	Downstream	Confined	4	L
High	Low	Midstream	Confined	4	M
High	**Low**	**Upstream**	**Open**	**4**	**H**
Medium	High	Downstream	Confined	1	L
Medium	High	Midstream	Confined	1	M
Medium	**High**	**Upstream**	**Open**	**1**	**H**
Medium	Low	Downstream	Confined	3	L
Medium	Low	Midstream	Confined	3	M
Medium	**Low**	**Upstream**	**Open**	**3**	**H**
Low	Low	Downstream	Confined	4	L
Low	**Low**	**Midstream**	**Confined**	**4**	**M-H**
Low	**Low**	**Upstream**	**Open**	**4**	**H**

Table 2. Summary of the factors that determine the extent of the impact of explosive weapons in space and time, according to different scenarios of baseline resilience. The magnitude, delivery method and contact of the explosive is assumed constant in each scenario. Entries in bold are those with the highest magnitude.

A close reading of the table reveals a number of relevant dynamics. The first is that the greatest impact (i.e. those scenarios classed as 'open' in the space column, and graded '3' or '4' in the time column) occur where the explosive weapons is used on an 'upstream' part of a service that is low both in terms of quality and in capacity to respond. This confirms conventional thought on the subject, i.e. that the attacks which are the most likely to cause direct or reverberating effects over the largest area and for a prolonged period of time are those on the supply-end (i.e. upstream) infrastructure, especially if this is already degraded.

Second, the expected impact of explosive weapons *across space* is found to be shaped primarily by the hierarchy of the component within a service. That is, the spatial extent of the reverberating effects of explosive weapons on 'downstream' elements of an infrastructure system can be expected to be 'confined' (typically to a localized neighbourhood or even household level). The reverberating effects of explosive weapons on 'upstream' elements of a service are more open – limited only by the extent of the infrastructure of the network, which often spans dozens of kilometres and can serve upwards of hundreds of thousands of people.

Third, the expected impact of explosive weapons on urban services *in time* is found to be determined primarily by the baseline resilience of the service. That is, the reverberating effects upon any component of a service (whether people, hardware, or consumables; or located up, mid, or downstream) is likely to be shorter when the pre-attack quality of the service and its ability to respond is high. Reverberating effects of explosive weapons on the service are expected to last much longer when the baseline conditions of the service are poor. Generally, a service that is already vulnerable is more likely to be disrupted for a longer period than one that is robust, in other words (and can span from days to decades, and distinct from other reverberating effects (e.g. on public health, markets, etc), which might not be similarly bound). .

There is also considerable differentiation of the impact on time within each scenario. For services of the same baseline quality, for example, the magnitude of the reverberating effects varies directly with the ability to respond. Likewise, in situations of equal ability to respond, the magnitude of the reverberating effects varies directly with the quality of service.

[Head 1] Implications for proportionality and precaution in attack

The analysis has demonstrated how the impact of explosive weapons on any component of a service can be direct and reverberate within the same service or on other services. The duration and spatial extent of the direct and reverberating effects depend primarily on the extent of the damage to the functionality of a service component. The overall impact across space varies significantly, being determined primarily by the hierarchy of the component suffering the direct effect (damage on upstream components typically having the most widespread impact). The duration of the overall impact is determined mainly by the pre-explosion operational resilience of the service, as measured in terms of system redundancies and emergency preparedness and response. More specifically, and in the majority of cases seen, the greatest impact of explosive weapons on urban services is a function of the extent of the damage to upstream or midstream infrastructure (i.e. that which produces or delivers the bulk of the service), the nature and extent of the reverberations downstream of the elements of any service component, the 'domino effect' onto others services, and of the time required to restore the service.

The findings hold a number of implications for the rules on proportionality and precaution in attack, as they shed light on what impact on urban services can be 'reasonably foreseeable'. As Robinson and Nohle discuss, the rules oblige attackers "to take into account the expected incidental loss of civilian life, injury to civilians or damage to civilian objects arising from a particular attack", which the ICRC interprets to include the foreseeable reverberating effects of an attack.[41] The relevant question when carrying out a proportionality assessment for an attack on a military objective expected to cause damage to a service is: to what extent are the direct impact and reverberating effects 'reasonably foreseeable'?

The analysis has emphasised that service hardware is the chief component of concern of the use of explosive weapons, and that upstream and midstream infrastructure have primacy within that particular service component. A number of features of such primary service hardware should be considered. First, the detailed layout of the service system is often only known by the staff of the service provider that operates the service (typically at the municipal level), even if the original layout is sometimes recorded in as-built plans or standard operating procedures. Regardless of whether an attack is planned with the luxury of time or a result of dynamic targeting (i.e. time sensitive), access to this level of information is not likely to be readily available. However, in some circumstances with time and experience a greater level of information and knowledge will have been acquired (e.g. in protracted conflict, or during periods of prolonged occupation), and hence could be expected to inform any proportionality assessment[42]. Given the fact that `collateral damage` is assessed, this analysis suggests that resource personnel can and should be used wherever possible to gain the knowledge of the basic layout and functioning of the service. In the absence of such information, the alternative is to rely on the expert opinion of engineers specialised in a particular urban service (i.e. water supply, wastewater collection and treatment, and power supply).

Second, it happens that most of this upstream and midstream infrastructure is identifiable, in that it is typically located at ground level and takes on familiar spatial or design patterns. For example, the clarifying tanks emblematic of water treatment plants are readily distinguishable for being circular and from about three to 15 metres in diameter. They are also quite distinct from conventional electrical power plants or conventional wastewater treatment plants. Secondary booster pumping stations and ground level and elevated water reservoirs are clearly distinguishable if not covered, and so also discernible to a trained eye.

[41] I. Robinson and E. Nohle, above note xxx.
[42] Which could include but is not limited to a collateral damage estimation.

If such infrastructure is identifiable from the air (or from the ground when in the line-of-sight), it follows that a weapons controller could be trained to distinguish it from other parts of an urban landscape.

Third, there is considerable specialist knowledge of the direct effects of the use of explosive weapons on urban services, at least on infrastructure. This lies with militaries,[43] local authorities,[44] and some humanitarian organizations[45]. In terms of both physical protection of critical infrastructure and preparedness for a particular event, it is also documented in internal or open-source publications.[46]

Given these three characteristics, even without access to the as-built plans of critical infrastructure, much of the impact caused by the explosive weapon upon urban services is reasonably foreseeable. The statement holds whether the weapons have 'wide-area effects' or not. However, such reverberating effects are not yet as routinely catalogued (or perhaps even conceptualised) by belligerents, local authorities, and relief agencies. Amongst other implications that are to be addressed in separate analysis,[47] then, the findings suggest that the process of carrying out a proportionality assessment that involves urban service infrastructure would benefit from: i) the direct and consistent engagement of specialised engineers within the targeting cell; and ii) greater familiarity of the weapons controller with services, infrastructure and systems in urban areas (and when possible in theatre). The latter will ensure a greater likelihood of identifying civilian objects (which are static), and associate them with the foreseeable reverberating effects (including those that are immediate and within systems).

The analysis holds two further implications for discussions about rules on proportionality and precaution in attack. It is worth returning to the articulation in footnote 17 of reverberating effects on *urban services* as a subset of the 'foreseeable reverberating effects of an attack' *in the general sense*, as described by Robinson and Nohle (this volume). The former are not only generally more bounded in space and over time as this analysis shows, they are also arguably even more easily foreseeable than the latter (which extend, according to the definitions employed here, beyond the reverberating effects on urban services themselves).

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[43] US Army. *Intelligence Support to Urban Operations*. US Army Intelligence Center and School, for the US Training and Doctrine Command: Headquarters, Department of the Army, Field Manual FM 2-914, 2008. and Patterson 2000

[44] e.g. the Southern Water Board, Lebanon (in 2006) and the Coastal Municipalities Water Utility (CMWU) in the Gaza Strip.

[45] e.g. the ICRC

[46] Canada, Public Safety (2010). *Risk Management Guide for Critical Infrastructure Sectors*. Version 1.0. Ottawa. Public Safety Canada; CEPS (2010). *Protecting Critical Infrastructure in the EU*. CEPS Task Force Report. Brussels. Centre for European Policy Studies; FEMA (2003). *Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings*. Risk Management Series. Washington DC. US Department of Homeland Security / FEMA 426.

[47] Including the protection offered by International Humanitarian Law. Initial discussions are to be found in Tignino, Mara (2016). *Water During and After Armed Conflicts: What Protection in International Law?* , Brill; Gisel, Laurent (2015). *The use of explosive weapons in densely populated areas and the prohibition of indiscriminate attacks*. 37th Round Table on Current Issues of International Humanitarian Law, Sanremo 4-6 September 2014, International Institute of Humanitarian Law.

Finally, the analysis further contributes to a related debate about the ability to mitigate the impact of explosive weapons on urban services (whether reasonably foreseeable or not). As the ICRC *Urban Services* report states, "(a)lthough the rules on the conduct of hostilities do not specifically state that an attacker must take account of the decreased capacity of essential services caused by previous attacks, to the extent that such decreased capacity is foreseeable, it must be taken into account".[48] The analysis has shown that the ability of a system to respond to damage or disruption is one of the key elements of the baseline conditions that determine the extent of the reverberating effects, most notably over time.

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ICRC. *Urban services during protracted armed conflict: a call for a better approach to assisting affected people*. International Committee of the Red Cross: Geneva, 2015.

[48] (2015: 40)