NUCLEAR EXPLOSIVES IN WATER-RESOURCE MANAGEMENT

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PERSPECTIVE

Nuclear explosives afford diverse tools for managing our water resources. These include principally: the rubble column of a fully contained underground detonation, the similar rubble column of a retarc, the crater by subsidence, the throwout crater of maximum volume (the latter either singly or in-line), and the ejecta of a valley-slope crater. By these tools, one can create space in which to store water, either underground or on the land surface--in the latter instance, to a considerable degree independently of the topography. Underground, one can accelerate movement of water by breaching a confining bed, a partition of a compartmented aquifer, or some other obstruction in the natural "plumbing system." Finally, on the land surface, one can modify the natural pattern of water flow, by canals excavated with in-line detonation. In all these applications, the potential advantage of a nuclear explosive rests chiefly in undertakings of large scale, under a consequent small cost per unit of mechanical work accomplished.

WATER STORAGE

Space created underground by a fully contained nuclear detonation is slightly less than 3 million gallons or 9 acre-feet (11,000 cubic meters) per kiloton of yield. Such is the volume of an initial cavity of detonation, of void spaces in rubble of a collapse chimney, and (approximately) of a subsidence crater. In most situations the present overall cost of such space would grossly exceed that of conventional land-surface storage, commonly by about an order of magnitude. However, the underground space would be free from loss by evaporation, the ever-present "tax" on water stored in land-surface reservoirs. Practically, underground storage space by nuclear detonation seems limited to special circumstances, such as (1) an urgent water requirement in a region whose rocks are massive and of inconsequential natural water content, but where infrequent surface runoff could be intercepted; or (2) a need to dispose of an especially noxious waste fluid which would be intolerable in the biosphere.

Storage space on the land surface, in a maximum-volume throwout crater, is several-fold greater than that in an underground cavity or rubble chimney, per kiloton of yield. Specifically, the crater space is about 8-fold greater than the chimney space at a yield of 1 kiloton, 6-fold greater at 10 kilotons, and 5-fold greater at 100 kilotons.

As a reservoir for water storage, the throwout crater is virtually independent of land form; generally, therefore, such storage can be sited principally or exclusively for maximum hydraulic efficiency. Costwise, crater space would be potentially competitive with conventional dam-and-reservoir space for volumes more than 5,000 to 10,000 acre-feet (about 10 million cubic meters), assuming all the apparent volume of the crater were usable. However, unless charging or evacuating is by pumping, the usable space may be only a small fraction of aggregate space--usable space being limited upward by the highest hydraulic grade line at which water feasibly can be diverted into the crater by gravity flow, and limited downward by the lowest hydraulic grade line at which the crater can be evacuated by gravity. Space above the upper limit would be inaccessible; that below the lower limit would be "dead." Either the upper limit or the lower limit might be fixed by the position of the natural water table.

As a tool for creating space, the throwout crater has two potential applications that are somewhat uncommon: in or alongside a stream channel, to trap sediment; and, off-channel and above hydraulic grade line, to provide storage for on-peak hydroelectric capacity.

Potentially the most efficacious nuclear means of creating space for water storage appears to be the slide dam, or the dam by ejection from a valley-side crater. Practical limitations on this means would rest largely in competitive engineering design, nuclear v. conventional, which is beyond the scope of this paper.

WATER MOVEMENT UNDERGROUND

Compared to most natural water bearing materials, the rubble column of a fully contained underground detonation, likewise that of a retarc, is very highly permeable indeed. Thus, suitably sized and placed to breach a confining bed, partition, or other obstruction to ground-water movement, the rubble column becomes a potential means for (1) under-draining a perched water body into the regional aquifer system; (2) discharging a confined water body, upward or downward, into any other aquifer of less head (hydrodynamic potential); or (3) integrating a compartmented aquifer system. The general purpose would be to accelerate recharge, or to increase or prolong the potential yield of developed or developable aquifers.

In all such applications, overall hydraulic performance is most likely to be limited, not by transmissibility of the rubble chimney, rather by natural transmissibilities elsewhere in the aquifer system. Thus, an adequate forecast of performance would require, prior to detonation, that natural hydrologic conditions be appraised widely and possibly exhaustively. The results of appraisal could be inconclusive. A further practical limitation is a potentially common necessity that the vertical run of a rubble column be matched closely to thickness and succession of the rock strata, with no more than nominal over-break beyond some certain stratigraphic zone. A sufficiently nice fit of rubble-column height and stratigraphic thicknesses may not be attainable.

An additional potential advantage of a rubble column is its so-called big-well aspect in massive rocks through which water moves "arterially" in rather widely spaced fractures or ramifying solution channels. Under such conditions the rubble column may intersect several such fractures or channels, and thereby increase the potential rate of water withdrawal (but not the perennial yield). Alternatively, in the big-well aspect, the rubble column would tend to accelerate recharge of, or dissipation of waste fluid into, an aquifer whose natural permeability is small.

Movement of water into the ground--that is, recharge--would tend to be accelerated by the rubble column of a retarc, by the dilated and up-turned wall rocks of a throwout crater, or possibly by the non-dilated collapse column of a subsidence crater. Determinative factors would include the permeabilities, thicknesses, and succession of strata in relation to depth reached by the retarc column or the crater, as well as depth to the aquifer.

WATER TRANSPORT ON THE LAND SURFACE

Effective re-distribution of the natural streamflow is the common requirement of water-resource management. Major works to such an end--canals for intra- or inter-basin diversion--conceivably can be constructed by simultaneous detonation of several nuclear explosives buried in line at a suitable spacing. Practicality of this nuclear application would appear to rest mainly in cuts at least a few hundred feet deep; a 1,000-foot depth of cut appears not impossibly large. Thus, for a major stream diversion, a straight rather than circuitous alinement commonly becomes feasible, independent of all except major land-form barriers.

PRACTICAL LIMITATIONS ON DETONATION

Beyond aspects of engineering design, which are much too complex to be summarized here, feasibility of any particular nuclear detonation is restricted by (1) moderate uncertainty as to dimensions of rubble column or crater produced by a given yield of energy; (2) side effects of detonation--ground motion, air blast (if any), and dispersal of radionuclides produced by the detonation; (3) comparative economics of nuclear v. conventional methods; and (4) legal considerations. The stringency of such limitations would be peculiar to environmental features at and surrounding each proposed detonation site; accordingly, comprehensive pre-shot assessment of the surroundings, possibly very widely, becomes necessary. Some perspective can be summarized here, in the inverse order of the categories just listed.

A nuclear detonation for a water-management purpose involves not only the obvious risk of liability for immediate injury to persons or damage to structures, but also the additional risk that might arise from delayed or prolonged infringement on the rights of individuals in water bodies whose natural behavior was modified. The immediate risk relates to ground motion in the case of a non-venting detonation; to air blast or dispersal of air-borne detonation products in the case of a venting detonation. Reasonably definitive criteria are at hand by which to minimize these immediate risks, in terms of remoteness of a detonation from centers of population or from structures. However, assuming a detonation of 100 kilotons or more, the ideal remoteness commonly may not be possible and some minor injury or damage might be inevitable. In this situation, standards by which to measure the injury or damage are currently neither universal nor reasonably precise. Thus, magnitude of the liability would at this time be difficult to ascertain. In regard to the delayed risk of infringed water rights, the minimum requirement would be a comprehensive and exhaustive appraisal of hydrologic conditions both before and after detonation. Even so, the kind or degree of infringement could be inconclusive and the magnitude of liability not determinable.

As to comparative economics, nuclear v. conventional, the speaker takes the present overall cost of a single nuclear detonation not exceeding 100 kilotons to be in the general order of $2 million; that of a detonation of greater yield only nominally more. This is the basis for the preceding generalizations that (1) water-storage space in a rubble column or in a standard crater-by-subsidence would not compete economically with space in a conventional reservoir on the land surface, and (2) storage space in a throwout crater would not compete in volumes less than 5,000 to 10,000 acre-feet (about 10 million cubic meters). Thus, the smaller storage spaces by nuclear detonation seem justifiable only by an urgency or an advantage that overrides non-economic cost. (On another hand, the larger nuclear undertakings involve potentially limiting side effects, which will be summarized.)

Comparative efficacy and economics of a rubble column v. a conventional drilled hole should be assessed carefully, be the scale of the project large or small. Take, for example, the concept that the classic Dakota artesian basin might be re-pressurized by breaching confining beds that intervene between the Dakota and Lakota aquifers, also, between these aquifers and the underlying Madison limestone. The concept derives from the recent showing by Swenson that the Dakota-Lakota overlap the Madison and, in the belt of overlap, are charged from the Madison. It appears technically feasible to breach the particular confining beds with rubble columns generated by nuclear detonations, each from a few hundred kilotons to possibly a few megatons. Even with population centers dispersed as in central and eastern South Dakota, sites that would both accommodate detonations so large and satisfy hydrologic requirements are not readily identifiable. On the other hand, the hydrologic effect of each rubble column could be duplicated by two conventional drilled holes of the diameter necessary for emplacing the nuclear explosive. The drilled holes would cost substantially less and would avoid both the uncertainties and the side effects of nuclear detonation.

In regard to radionuclides dispersed by a non-venting detonation in the ground-water environment, early and close-in concentration might greatly exceed the so-called maximum permissible. However, considering rates of radioactive decay, velocities of ground-water movement, and the degree to which specific nuclides would be adsorbed onto the water-bearing medium, concentration of all nuclides except tritium would generally not exceed "permissible" in water withdrawn several miles down-gradient from shot point. For each proposed nuclear detonation, however, a specific radiation-protection guide would need be determined for the particular environment. The specific guide might be less stringent than the "permissible" concentrations of Handbook 69, especially if none of the water would enter food or drink.

In a fission-fusion detonation, tritium becomes the critical and diagnostic nuclide. If it could enter the food chain, tritiated ground water generally should be withdrawn only from an aquifer of small permeability, with the point of withdrawal tens of miles down-gradient from shot point, so that residence time of the water in the aquifer would be at least a century. If use of the tritiated water were wholly separate from the food chain, a shorter residence time in the aquifer might be acceptable but the waste fluid resulting from the use would require disposal under acceptable public-health standards. Obviously, expected concentration and dispersal history of tritium would need be appraised with great care in the planning stage of each proposed fission-fusion detonation.

A venting detonation for a throwout crater or trench (for water storage, recharge, or transport) adds the complication of air-borne radionuclides dispersed by the wind. Seriousness of such dispersal would of course be peculiar to each detonation, to environmental features of the site, and to meteorologic conditions at shot time. Dispersal might be wide if nuclides fall into a major flowing stream, or greatly prolonged if nuclides fall first onto the land surface but subsequently are transported to streams by overland runoff. Complexities are many and beyond the scope of this paper.

Public acceptability of a nuclear detonation for a water-management purpose would depend to a considerable degree on severity of the attendant ground motion. As has been alluded to under the preceding discussion of liability, reasonably definitive criteria are at hand by which such severity can be anticipated. Assuming, however, that the feasible water-management detonation will be on the order of 100 kilotons or more, distance from shot point to centers of population or vulnerable structures might need be in the order of a few tens of miles. Sites so remote, but at the same time effective for a common water-management purpose, are unlikely to be widely available.

Allusion has been made to the common requirement for a nice fit between dimensions of an underground rubble column and stratigraphic dimensions of the environment. Again assuming that the feasible water-management detonation will be of moderately large yield, rather than small yield, even the moderate present uncertainty in dimensions of rubble column or crater appears commonly to preclude the nice fit required.

CONCLUSION

Considering both the practical and the technical limitations that have been outlined, it seems that nuclear detonation for water-resource management is likely to be practicable only in unusual hydrologic settings, or under an urgency that overrides economic or technical disadvantage.

The concepts here summarized briefly have been developed at length in two antecedent documented papers, as follows:

Piper, A. M., and Stead, F. W., 1965, Potential applications of nuclear explosives in development and management of water resources--Principles: U.S. Geol. Survey rept. TEI-857, 128 p.

Piper, A. M., 1968, Potential applications of nuclear explosives in development and management of water resources--Preliminary canvass of the ground-water environment: U.S. Geol. Survey rept. TEI-873, 173 p.