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ORIGINAL ARTICLE

Effects of Urbanization on Stream Channels

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ABSTRACT: In response to urbanization, stream channels can undergo substantial changes, especially if channel stabilization measures are not instituted in the early stages of urbanization. Urbanization causes (1) significant increases in peak discharges, total runoff volume, and frequency of bank-full discharges; (2) the steepening of channel slopes if and where natural channels are straightened to accommodate new development; (3) reduction in sediment bed load from fully developed areas; and (4) eroding and degrading natural channels. These factors, in combination, create conditions that are conducive to channel instability—widening (erosion) and deepening (degradation) in most reaches and debris and sediment accumulation (aggradation) in others. To fully evaluate the proper channel morphological processes when undertaking a basic design or protective measure project, it is necessary to have some knowledge of channel stability concepts. The normal objective of channel stability evaluation is identification of principal channel hydraulic parameters influencing the stability of the channel. After identifying these parameters under existing channel conditions, the values of these parameters under future conditions are estimated. For areas undergoing urbanization, one of the most important changes is an increase in the volume, frequency, and flow rates of water in main channels. Stability analysis is then performed based on hydraulic parameters for anticipated future conditions, and stabilization measures are planned to minimize potential channel erosion under future conditions. There are a number of quantitative methods of channel stability analysis available to the designer including allowable velocity methods, tractive force calculations, and Leopold channel configuration relationships, among others. The hallmark of urbanization is increased imperviousness. Planning of a major drainage system must account for changes in hydrology, hydraulics, and channel stability that urbanization produces. As a result, the design of the major drainage system must be based on fully urbanized conditions to assure adequate capacity for conveyance of the major (e.g., 100-year) flood event. It is also important to recognize that the higher sediment loads during the process of urbanization (during construction) may shift the channel toward an equilibrium state that is different from the desired stable channel balance for the urbanized basin.

Keywords: Stream Channels; Major Drainage; Initial Drainage; Urbanization

1. INTRODUCTION

Storm drainage is a part of the total urban environmental system. Therefore, storm drainage planning and design must be compatible with comprehensive regional plans. A master plan for storm drainage should be developed and maintained in an up-to-date fashion at all times for each urbanizing drainage watershed in the region. The planning for drainage facilities should be coordinated with planning for open space and transportation. By coordinating these efforts, new opportunities may be identified that can assist in the solution of drainage problems.

Natural drainageways should be used for storm runoff waterways wherever feasible. Major consideration must be given to the floodplains and open space requirements of the area (White 1945).

Every urban area has two separate and distinct drainage systems, whether or not they are actually planned and designed. One is the initial system, and the other is the major system. To provide for orderly urban growth, reduce costs to future generations and avoid loss of life and major property damage, both systems must be planned, properly engineered and maintained.

1 THE DRAINAGE SUBSYSTEM

1.1 Planning

Planning of the urban storm runoff system is a very important step that requires a comprehensive understanding of city planning, drainage planning, and many of the social, technical, and environmental issues embedded in each watershed.

Urban storm runoff is a subsystem of the total urban system. It is an integral part of the urban community and should be planned as such. The drainage engineer must be included in all urban planning from the beginning. When drainage planning is done after all the other decisions are already made as to the layout of a new subdivision or commercial area or of the transportation network, drainage and urban space allocation problems often result that are costly and difficult to correct.

Storm runoff will occur when rain falls or snow melts no matter how well or how poorly drainage planning is done. Drainage and flood control measures are costly when not properly planned. Good planning results in lower-cost drainage facilities for the developer and the community and a more functional community infrastructure (Jones 1967).

Consideration of multiple uses and multiple benefits in drainage planning and engineering can reduce drainage costs and increase benefits to the urban system. One way to ensure maximum consideration of these multiple uses is by preparing master plans for drainage so that the overall effort is coordinated with other predetermined objectives (ASCE and WEF 1992).

During the master planning phase, major decisions are made as to design velocities, location of structures, open space set-asides for drainage, integration with recreation, means of accommodating conflicting utilities, and potential alternate uses for open channels, detention, and water quality facilities. It is also at this time that decisions need be made on the use of downstream detention storage, either off-stream or channel ponds or reservoirs. Upstream storage and land treatment should also be evaluated.

1.2 Planning philosophy

Planning of urban drainage facilities should be based upon incorporating natural waterways, artificial channels, storm sewers, and other drainage works into the development of a desirable, aesthetic, and environmentally sensitive urban community, rather than attempting to superimpose drainage works on a development after it is laid out, as is often done with water supply and sanitary sewer facilities. Surface drainage, unlike water and sanitation systems, must be integrated early into the fabric of the urban layout.

Urban drainage should be considered on the basis that two separate and distinct drainage systems exist. These are the initial drainage system and the major drainage system.

The initial system consists of grass and paved swales, streets and gutters, storm sewers, and smaller open channels. This is the system that, if properly planned and designed, will eliminate many "complaint" calls to the city or county. It provides for convenient drainage, reduces costs of streets, and directly affects the orderliness of an urban area.

A well-planned major system can reduce or eliminate the need for underground storm sewers, and it can protect the urban area from extensive property damage, injury, and loss of life from flooding. The major system exists in a community whether or not it has been planned and designed and whether or not development is situated wisely in respect to it. Water will obey the law of gravity and flow downhill to seek its lowest level whether or not buildings and people are in its way.

The planning process can best serve the community by making sure that nature’s prescriptive easements are maintained along major drainage routes. Here, floodplain delineation and zoning are tools that should be used freely. Small waterways and gulches lend themselves to floodplain regulations in the same manner as larger creeks.

Reshaping channel areas along small waterways is often not required, except to provide grade control, protection of certain vulnerable areas (such as the channel toe and outer banks), or unless they are in a degraded or deteriorated condition. The practice of straightening, narrowing, and filling major drainage ways such as gulches, dry streams, and other natural channels is not recommended for general use in drainage way master plans. The urban storm water planning process should attempt to make drainage, which is often a resource out of place, a “resource in place” which can contribute to the community’s general well-being.

1.3 Drainage Management Measures

Urban drainage and flood control planning should consider the following management measures:

1. Appropriate measures to limit development of land that is exposed to flood damage including:

a. Enacting floodplain management or other restrictive ordinances (i.e., building, subdivision, housing and health codes).

b. Acquiring developed property in built-up areas.

c. Pre-empting development of vacant flood fringe areas by public acquisition of land where appropriate for good drainage and community planning.

2. Appropriate measures to guide proposed development away from locations exposed to flood damage including:

a. Developing floodplain regulations.

b. Using warning signs.

c. Limiting access to flood-prone areas.

d. Using setbacks from channel banks.

e. Withholding public financing from flood area development.

f. Withholding utilities (electricity, water, sewers, etc.) from flood area development.

g. Examining equivalent alternative sites.

h. Maintaining low property assessment for tax purposes allowing flood-prone land to economically lie idle.

i. Providing incentives for floodplain dedication to the public such as density credits.

3. Appropriate measures to assist in reducing individual losses by flooding including:

a. Structural flood abatement devices.

b. Flood-proofing buildings.

c. Early warning systems.

d. Emergency preparedness plans (e.g., sandbagging, evacuation, etc.).

e. Ongoing maintenance of the minor and major drainage systems.

f. Disaster relief (funds and services).

g. Tax subsidies (i.e., ameliorating assessments).

Furthermore, good urban drainage planning practices and management procedures should make it possible to initiate:

1. Land use planning that recognizes flood hazards and flood damage and the value of the riparian zones that often occupy natural major drainage way routes.

2. A plan for expansion of public facilities that recognizes the implications of flood hazards for:

a. Sewer and water extensions.

b. Open space acquisition.

c. Transportation.

3. Implementation measures that demonstrate an existing or proposed floodplain management program including, where appropriate:

a. Building codes, zoning ordinances, subdivision regulations, floodplain regulations, and map regulations with flooding encroachment lines. These should be consistent with land use recommendations discussed earlier, incorporating flood-proofing requirements and reserving areas used in accordance with flood control recommendations.

b. Participation in regional land use planning.

c. Participation in available floodplain management services, including flood warning systems.

d. Cooperation in flood damage data collection programs.

4. Use of major public programs that are available (e.g., urban renewal, public health, open space, code enforcement, highway programs and demonstration programs).

5. The administrative devices created to undertake and implement a floodplain management program including a commitment of personnel, financing, and other resources.

1.4 Water Quality

Drainage planning for quantity (rate and volume) should proceed hand-in-hand with planning for water quality management. Generally, in urban areas, water quantity and water quality are inseparable. Another essential aspect of water quality protection is stream channel stability. Unstable channels can experience significant degradation and aggradation, both of which can damage aquatic life. Consequently, channel stability must be assured during the planning process.

2 EARLY PLANNING ADVANTAGES

2.1 Advantages

There are many advantages to the developers, residents, and local governmental agencies when drainage planning is undertaken early. These advantages include lower-cost drainage facilities and facilities that provide integrated benefits to the community. The drainage engineer, planner, and the entire design team should work in close cooperation to achieve maximum urban benefits.

Good urban drainage planning is a complex process. Basic planning considerations that should be taken up early include planning for the major drainage system, the initial drainage system, and the environment.

2.2 New Development

When planning a new subdivision for residential purposes, various drainage concepts should be evaluated before decisions are made as to street location and block layout. It is perhaps at this point in the development process where the greatest impact can be made as to what the drainage facilities will cost and how well they will do their job. When flood hazards are involved, the planning consultant should take these hazards into consideration in land planning to avoid unnecessary complications with local planning boards and governments.

Planners, both governmental and private, are encouraged to confer and work with the drainage engineer. The earlier drainage problems are identified and planned for, the better the final resulting plan will be. Compromising on drainage ways in a new development may appear to have short-term benefits, but long-term urban interests suffer as a result. Good drainage policy and practices should be uniformly and consistently applied.

2.3 Get the Facts

The importance of obtaining the facts, including technical and community-based information that affects the drainage program, cannot be overemphasized even in the early planning stages of development. With the aid of the collected facts, defining the objectives of the drainage system, as well as the problems that will be encountered in implementing the drainage plan, can be the most important step in the planning process. As the planning process progresses, the defined objectives will need to be re-evaluated for affordability and practicability of implementation, sometimes requiring adjustment of the initial set of objectives.

2.4 Regulatory Considerations

One of the essential elements of early planning is to address regulatory requirements at the federal, state and local level. Drainage projects will frequently trigger the need for environmental permits related to (for example): wetlands and "Waters of the United States;" stormwater discharges; dewatering discharges; and local water quality, wetland or other protection ordinances. A solid understanding of these and other regulatory programs is imperative, as they can significantly affect the design, construction and long-term maintenance of channels, ponds, wetlands, and other facilities.

Figure 1. An engineered wetland channel can serve as a filter for low flows and yet carry the major flood event without damage.

3 CONSIDER DRAINAGE BENEFITS

3.1 Benefits

The planner should be cognizant of the additional benefits that can be derived from a good urban drainage plan. It is generally recognized that an urban area that has well-planned drainage facilities is usually an area that experiences orderly growth.

Some of the additional benefits that are derived from good urban drainage systems are:

1. Benefits to upstream property owners resulting from elimination of downstream constrictions and increased conveyance capacity.

2. Reduced problems to downstream property owners and receiving systems resulting from managed runoff and stable waterways.

3. Improved water quality.

4. Protection and enhancement of environmentally sensitive areas.

5. Reduced street maintenance costs.
6. Reduced street construction costs.
7. Improved traffic movement.
8. Improved public health and environment.
9. Lower-cost open space.
10. Lower-cost park areas and more recreational opportunities.
11. Development of otherwise undevelopable land.
12. Opportunities for lower building construction cost.
13. Controlled rising groundwater table after urbanization.

Professionals from other disciplines, including urban hydrologists, sociologists, economists, traffic engineers, civil engineers, public health professionals, attorneys, geographers, ecologists, landscape architects, and others can contribute to the formulation of plans for additional benefits.

4 MASTER PLANNING

4.1 Master Plan

A master plan is an overall plan into which the details of other specific plans are fitted, providing overall guidance for future actions and improvements for all or part of an evolving watershed. It is generally a regionally conceived plan based on examination of the total system that, with the aid of public participation, bridges a variety of perspectives and jurisdictional boundaries. It is a road map for future drainage and flood control watershed actions, irrespective of political boundaries.

A drainage master plan for an urbanizing area is helpful to both the developer and the municipality. The drainage master plan must be based on good environmental design techniques and address the goals and needs of the urban area. It should not be prepared only on the basis of drainage hydraulics and not be limited to moving storm water runoff from one location to another.

A master plan for drainage will only be effective if it is coordinated with planning for open space, transportation, water quality, urban wildlife, and other urban considerations.

4.2 Uniformity

A uniform approach to master planning of drainage in a region brings better results than when different approaches are utilized by each planning effort, depending upon the particular planning team's past experiences and training.

5 PLANNING FOR THE FLOODPLAIN

5.1 Floodplains

Planning addresses many issues that deal with floodplains and the necessity of floodplain zoning. It is necessary to understand the nature and concept of floodplain regulation before serious floodplain management planning can proceed intelligently. The planner must also consider the national flood insurance program, set forth in the National Flood Insurance Act of 1968, as amended (NFIA 1968).

Figure 2. Use of uniform design standards represents a reasonable standard of care for urban flood channels.

5.2 Concept of Floodplain Regulation

On any floodplain, nature possesses, by prescription, an easement for intermittent occupancy by runoff waters. Man can deny this easement only with difficulty. Encroachments upon or unwise land modifications within this easement can adversely affect upstream and downstream flooding occurrences during the inevitable periods of nature's easement occupancy.

Government has a responsibility to protect the public's health and safety. Thus, it is implicit that government may permit unwise occupancy or use of the natural easement only at the risk of incurring liability.

Urbanization typically modifies the natural hydrologic and water quality response of its drainage ways. Because urbanization usually proceeds in accordance with land use rules and land development regulations prescribed by local government and with the review and approval of detailed development plans, local government in effect becomes a party to the inevitable hydrologic modifications. It follows that a community cannot disclaim liability from consequences of such development, either upon the developed area itself or downstream there from.

Floodplain regulation is the government's response to limit its liability along natural drainage ways and is an exercise of its health and safety protective function. The concept of the existence of a natural easement for the storage and passage of floodwaters is fundamental to the assumption of regulatory powers in a definable flood zone. Floodplain regulation, then, must define the natural easement's bound-aries and must delineate easement occupancy that will be consistent with total public interests.

6 PLANNING FOR MAJOR DRAINAGE

6.1 Major Drainage

The major drainage system planning is the key to good urban drainage in newly developing areas. The general lack of good, open-surface major drainage in older urban areas often requires expensive storm sewer retrofit projects.

A major conduit or channel has an impact upon an urban area, and much depends upon its proper functioning. It is usually a box culvert, a large pipe, or an open channel. As an open channel, it may be a stabilized natural waterway, a modified natural channel, or an artificial channel with grass or other lining. The character of the major drainage way often changes from reach to reach to account for neighbourhood needs and general environmental requirements.

The planner and designer have great opportunities when working on major drainage ways to help provide a better urban environment for all citizens. The challenges and opportunities are particularly great for those having the opportunity to plan and design works in core areas of cities.

The conceptual design of a major drainage way channel or conduit is that portion of the engineer's job that is most important and that has the greatest effect on the performance and cost of the works. Imagination and general hydraulic experience of the engineer are the most important tools in the preliminary planning and design stage.

6.2 Initial Route Considerations

A preliminary estimate of the design rate of flow is necessary to approximate the channel's or conduit's capacity and size. This estimate can be made by comparisons with other similar basins where unit rates of discharge have been computed or by computing preliminary hydrographs.

Routing of the major drainage way is usually a straightforward matter of following the natural valley thalweg (i.e., the lowest point in the drainage way, sometimes also called channel invert) and defining it on a map. In many urbanized areas, however, there is no thalweg, or the thalweg has been filled and built upon. For these cases, it is necessary to determine many factors before the route is chosen. A meeting should be held with the owner and with the appropriate government officials to explain the routes studied, the conclusions, and the choice. At the same time, the types of channels or conduits being considered should be presented and suggestions or concurrence should be obtained. A dialogue with citizen groups is encouraged where various alternates can be explained.

6.3 The Master Plan

The major drainage master plan must be true to its name to be effective in urban drainage. It must be a team consensus with thorough attention to engineering concepts and details. The completed plan must be suitable for day-to-day use by local and regional governmental administrators.

The master plan portion of the planning phase is where major decisions are made as to design velocities, location of structures, means of accommodating conflicting utilities, approaches to minimize adverse environmental impacts and the potential alternate uses in the case of an open channel, among others.

The master plan is also where decisions need be made on the use of downstream detention storage, either off-stream or channel ponds or reservoirs. Upstream storage should also be evaluated along with BMPs for both quantity and quality.

6.4 Open Channels

Open channels for use in the major drainage system have significant advantages in regard to cost, capacity, multiple uses for recreational and aesthetic purposes, environmental protection/enhancement, and potential for detention storage. Disadvantages include right-of-way needs and the need for more frequent maintenance. Careful planning and design are needed to minimize the disadvantages and to increase the benefits.

Channel instability is a well-recognized problem in urbanizing areas because of the significant increase in low flows, storm runoff flow rates and volumes, and erosion along the waterways that cause increased sediment concentrations. The volume of storm runoff, peak discharge rate, and frequency of bank full discharges from an urban area are usually significantly larger than under historic conditions (Leopold 1994; Urbonas 1980; ASCE and WEF 1992; and WEF and ASCE 1998). A natural channel must be studied to determine what measures are needed to avoid future bottom scour and bank cutting. Structural measures can be implemented that will preserve the natural appearance, minimize cost, and assure proper channel function during large events. These include features such as grade control structures, drop structures, and bank stabilization.

In cases of a meandering channel, it may be necessary to provide a buffer zone outside of the floodway or floodplain to account for future channel movement. Likewise, where a deep, incised channel exists, a buffer zone allowance should be provided for bank sloughing and future channel modification by creating a setback line computed at a bank slope of 4(H) to 1(V) measured from the channel bank's bottom.

The ideal channel is one shaped by nature over a long period of time. Unfortunately, urbanization changes the hydrology that has shaped the channel, which, in turn, destabilizes it. Providing for features to keep a natural channel from rapid degradation is an important part of any master plan. The benefits of a stabilized natural channel can include:

1. Lower flow velocities, resulting in longer concentration times and lower downstream peak flows.
2. Channel and adjacent floodplain storage that tends to decrease peak flows.
3. Lower maintenance needs.
4. Protection of riparian and aquatic habitat.
5. A desirable greenbelt and recreational area that adds significant social benefits.

While recognizing the need for at least some stabilization measures to address the hydrologic changes caused by urbanization, the closer an artificial channel character can be made to that of a natural channel, the greater the public acceptance.

In many areas about to be urbanized, the runoff has been so minimal that well-defined natural channels do not exist. However, subtle low areas nearly always exist that provide an excellent basis for location and construction of channels. Good land planning should reflect even these minimal drainage ways to reduce development costs and minimize drainage problems. In many cases, wise utilization of natural water routes in the development of a major drainage system will eliminate the need for an underground storm sewer system.

A wide variety of channel types are available to the design team, depending on good hydraulic practice, environmental design, sociological impact, basic project requirements and other factors. The actual choice must be based upon a variety of multidisciplinary factors and complex considerations that include, among others:

1. Hydraulic Factors
   - Slope of thalweg
   - Right-of-way
   - Capacity needed
   - Basin sediment yield
   - Topography
   - Ability to drain adjacent lands
   - Permitting requirements
2. Structural Factors
   - Costs
   - Availability of material
   - Areas for wasting fill
3. Environmental Factors
   - Water quality
   - Neighbourhood character
   - Neighbourhood aesthetic requirements
   - Needs for new green and riparian areas
   - Street and traffic patterns
   - Municipal or county policies
4. Sociological Factors
   - Neighbourhood social patterns
   - Neighbourhood children population
   - Pedestrian traffic
   - Recreational needs

Prior to choosing the channel type, the designer should be sure to consult with experts in related fields in order that the channel chosen will create the greatest overall benefits. When practical, the channel should have slow flow characteristics, be wide and shallow, and be natural in its appearance and functioning.

Grass-lined channels, wetland bottom channels, and bioengineered channels with adequate structural enhancement may be the most desirable artificial channels. The channel storage, lower velocities, environmental benefits, and sociological benefits obtainable create significant advantages over other types. The design must give full consideration to aesthetics, sediment deposition, water quality, maintenance, scour, and hydraulics.

Many open waterways in region have experienced the effects of urbanization and are often steep-banked gulches that have erodible banks and bottoms. On the other hand, a number of natural waterways exist in the northern and eastern parts of the District that have milder slopes, are somewhat stable, and are not in an obvious state of degradation. However, for either type of channel, when it begins to carry storm runoff from an urbanized area, the changed runoff regime will result in new and highly active erosional tendencies. Careful hydraulic analysis of natural channels must be made to foresee and counteract these tendencies. In nearly all cases, some modification of the channel will be required to create a more stabilized condition so it can handle changes to surface runoff created by urbanization.

With most area natural waterways, it is necessary to construct grade controls or drop structures at regular intervals to decrease the thalweg (channel invert) slope and control erosion. When site conditions are conducive, channels should be left in as near a natural condition as feasible, subject to the requirement of demonstrated stability during the major event. Extensive channel modifications should not be undertaken unless they are found to be necessary to avoid excessive erosion with subsequent sediment deposition downstream and water quality deterioration.

Because of the decided advantages that are available to a community by utilizing natural waterways for urban storm drainage purposes, the designer should consult with experts in related fields for the method of development. It is important to convene a design team to develop the best means for using a natural waterway. Sometimes it will be concluded that park and greenbelt areas should be incorporated into the channel works. In these cases the usual constraints of freeboard depth, curvature, and other rules applicable to artificial channels may be different or may not apply. For instance, there are significant advantages that may accrue if the designer incorporates relatively frequent (e.g., every five years) overtopping of the formal channel, thus creating localized flooding of adjacent areas that are laid out and developed for the purpose of being inundated during the major runoff peak.

Figure 3. A wide-open waterway carries floodwater at modest depths while maintaining low velocities to inhibit erosion.

7 PLANNING FOR INITIAL DRAINAGE

7.1 Initial Drainage

Planning and design for urban storm runoff must be considered from the viewpoint of the regularly expected storm occurrence, which includes the initial storm and the major storm. The initial storm has been defined for the area served by the District to have a return frequency ranging from once in 2 years to once in 10 years. The major storm has been defined to have a return period of 100 years. The objective of major storm runoff planning and design is to reduce the potential for major damage and loss of life. The initial drainage system is necessary to reduce inconvenience, frequently recurring damages, and high street maintenance and to help create an orderly urban system with significant sociological benefits.

The initial system is sometimes termed the "convenience system," "minor system," "local system," "collector system," or "storm sewer system."

The initial drainage system is that part of the storm drainage system frequently used for collecting, transporting, and disposing of snowmelt, miscellaneous minor flows, and storm runoff up to the capacity of the system. The capacity should be equal to the maximum rate of runoff to be expected from the initial design storm.

The initial system may include a variety of features such as swales, curbs and gutters, storm sewer pipes, open drainage ways, on-site detention, "minimized directly connected impervious area" features, and water quality BMPs.

7.2 Streets

Streets serve an important and necessary drainage service, even though their primary function is for the movement of traffic. Traffic and drainage uses are compatible up to a point, beyond which drainage is, and must be, subservient to traffic needs.

Gutter flow in streets or flow in adjacent swales is necessary to transport runoff water to storm inlets and to major drainage channels. Good planning of streets can substantially help in reducing the size of, and sometimes eliminate the need for, a storm sewer system in newly urbanized areas.

Design criteria for collecting and moving runoff water on or adjacent to public streets are based on a reasonable frequency of traffic interference. That is, depending on the character of the street certain traffic lanes can be fully inundated during the initial design storm return period, usually once each two years. However, during this design period, lesser storms occur that will produce runoff, which will inundate traffic lanes to some smaller degree.

Drainage practices as related to streets are dependent on the type of street use and construction.

Classification of streets is based upon traffic volume, parking practices, design and construction, relationship to cross streets, and other criteria. The classification adopted for use herein includes:

- Local/residential.
- Collector.
- Arterial.
- Freeway.

Streets should be classified with respect to pedestrian traffic as well as vehicular traffic. As an example, streets that are classified as local for vehicles and located adjacent to a school are arterials for pedestrian traffic. The allowable width of gutter or swale flow and ponding should reflect this fact.

Inverted crown or "dished" streets shall not be utilized. The dished street design violates the basic function of a street: that of a safe vehicular traffic carrier.

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