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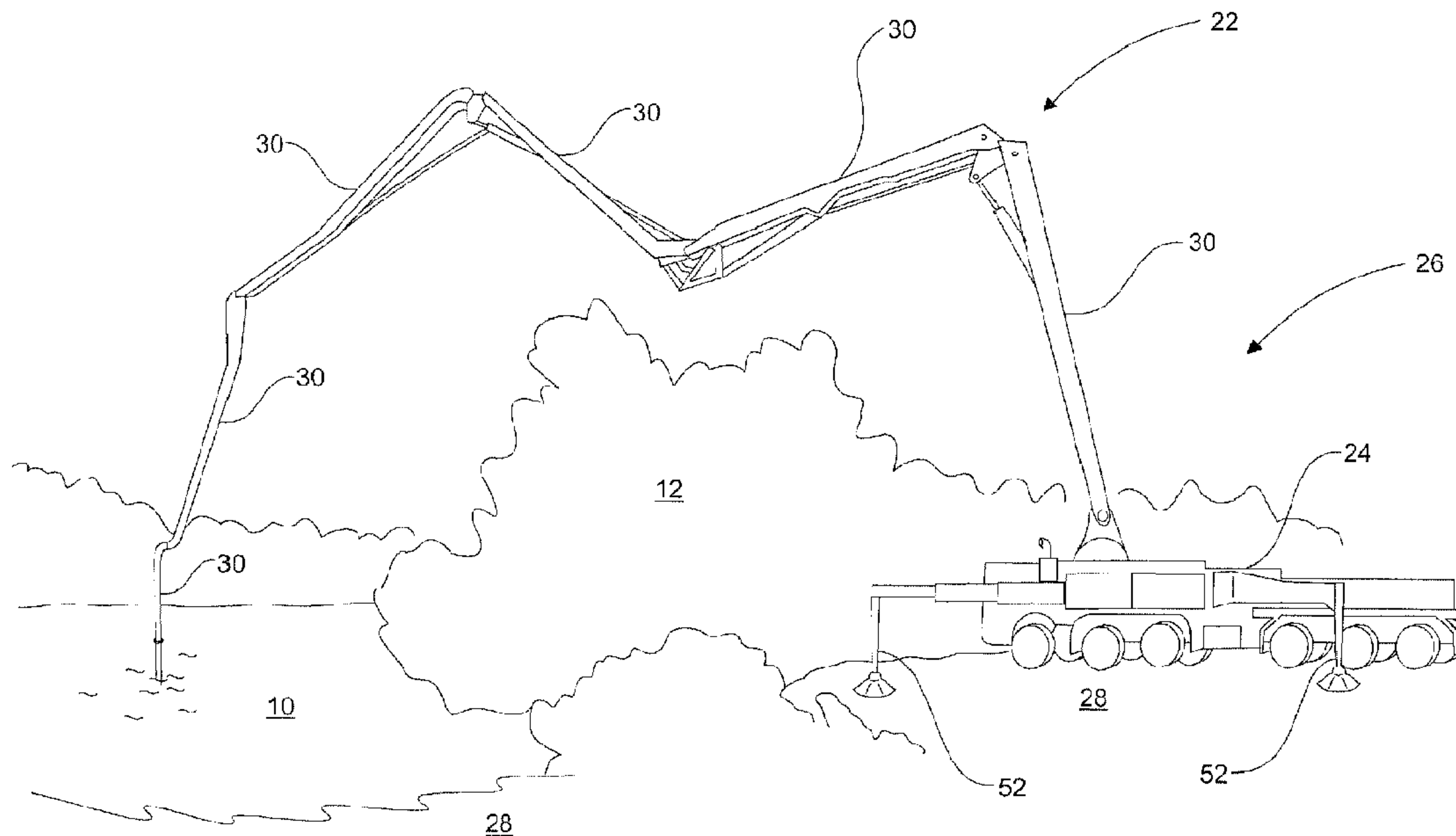
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(54) **Titre : PROCÉDE, APPAREIL ET SYSTEMES D'ASSAINISSEMENT D'ETANG**
(54) **Title: METHODS, APPARATUS AND SYSTEMS FOR POND REMEDIATION**



(57) **Abrégé/Abstract:**

Apparatus for extended-reach remediation of a pond by removal of pumpable materials such as deposited sediment has a base and a rotatable multi-articulated boom to which a pump is connected at the distal end. The boom has a reach which exceeds the reach of conventional remediation apparatus and may be as long as 50m or greater for reaching over obstacles between the base and the pond. The base can be stationary or it can be mobile or self-propelled for repositioning the apparatus about the perimeter of the water body or to platforms which are built within the pond and accessible by accessways when the pond is filled with water. The pump is lightweight so as not to affect the overall apparatus stability when the boom is fully extended. Geo-locating apparatus assists with mapping the remediation operation. Further, additional accessories can be connected to the end of the boom, such as fluid jets for controlling the fluid properties of the pumpable materials and a blender for shredding vegetation or other non-pumpable materials to render them pumpable.

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ABSTRACT

Apparatus for extended-reach remediation of a pond by removal of pumpable materials such as deposited sediment has a base and a rotatable multi-articulated boom to which a pump is connected at the distal end. The boom has a reach which exceeds the reach of conventional remediation apparatus and may be as long as 50m or greater for reaching over obstacles between the base and the pond. The base can be stationary or it can be mobile or self-propelled for repositioning the apparatus about the perimeter of the water body or to platforms which are built within the pond and accessible by accessways when the pond is filled with water. The pump is lightweight so as not to affect the overall apparatus stability when the boom is fully extended. Geo-locating apparatus assists with mapping the remediation operation. Further, additional accessories can be connected to the end of the boom, such as fluid jets for controlling the fluid properties of the pumpable materials and a blender for shredding vegetation or other non-pumpable materials to render them pumpable.

1 **“METHODS, APPARATUS AND SYSTEMS FOR POND REMEDIATION”**

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BACKGROUND

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Embodiments disclosed herein relate to systems and methods for removing liquidized materials from bodies of fluid and, more particularly, to apparatus and methods for removing sediment and associated matter from water reservoirs, ponds or the like.

It is well known, in storm water and industrial liquid waste management systems, to provide ponds to receive contaminated water flows for treatment prior to discharging the treated water into local watersheds or sewers, where permitted. Treatment typically entails a first step of enabling fluid residence within the pond to allow for a time dependent, water quality improvement process to take place, such as sedimentation of suspended matter including, but not limited to, silt, sand and clay. The initial residence step may include additional treatment or the additional treatment may be included in one or more subsequent steps, such as secondary and tertiary steps, to encourage composting, nutrient removal and the like for further clarifying the treated water.

In urban areas, municipal water ponds typically form a water feature about which residences may be located. Many of these constructed water bodies, particularly those in municipal settings, are of a size and configuration such that

1 most of the pond surface area is within a fixed distance, for example about 50m, of
2 the pond's edge. Other ponds, such as industrial ponds, tailings ponds used in
3 mining or oilsands processing or a variety of other industrial processes, are typically
4 similarly sized. Further, the constructed water bodies may have components
5 associated therewith from which much of the surface area of the pond is within the
6 fixed distance. Over time, solid materials such as sediment may build up in these
7 ponds, reducing the pond's utility. Applicant believes that the sediment which
8 accumulates in these ponds tends to be of a uniform, slurry consistency.

9 A conventional remedy to pond sediment accumulation includes
10 draining the pond in order to provide access for excavating machines and
11 conveyance vehicles to remove and dispose of the sediment. One complication to
12 such excavation processes is the close proximity of the residences, construction
13 sites, landscaped terrains with trees or other valuable vegetation or other features
14 which may surround the perimeter of the pond and restrict access thereto by the
15 excavation equipment and sediment disposal carriers.

16 In municipal environments, remediation processes are often
17 scheduled during the winter. The pond may be drained into the municipal sewer
18 system if drainage onto natural water ways is not permitted during the winter
19 months.

20 A plurality of backhoes is often employed in a chain arrangement to
21 shovel sediment from a point in the pond to a point closer to the shore and from
22 there to a point on shore for loading onto trucks. The process can, for example,

1 take from 1 to 2 months for remediation of a typical storm water pond. Current cost
2 is about \$3M for removal of sediment from each pond. Sediment removal is
3 performed for each pond once every 10 to 20 years or so. Furthermore, Applicant
4 believes that a current cost of disposing of the removed sediment is about \$2M for
5 each pond, particularly if special disposal procedures are required, such as
6 contaminated material landfill disposal as may be required for some stormwater or
7 industrial water ponds.

8 The conventional remediation process, as described, is laborious,
9 requires a long time to complete and is very expensive. Disposal of the drained
10 water may be impractical due to government regulations and permits. Conventional
11 pond remediation also tends to be disruptive to the peace and enjoyment of the
12 local residents. Disposal of removed remediation materials, such as the sediment
13 slurry, is expensive and impractical. Disposal typically involves a process of
14 spreading slurry on other lands to allow the slurry to dry or thickening of the slurry
15 using specialized dewatering equipment.

16 Shoreline and barge-mounted dredging has been exploited to remove
17 materials from the bottom of water bodies as taught in US Patent 4,942,682 to
18 McDowell. McDowell utilizes a self-contained, reversible dredging module adapted
19 for use as an attachment to a conventional backhoe machine, thereby creating a
20 two-segment backhoe.

21 Applicant believes that access to the pond surface using such a two-
22 segment backhoe is limited, such as to about 15m from the shore. As the surface

1 of municipal ponds, industrial ponds or tailings ponds used in mining, oilsands and a
2 variety of other industrial processes have a surface area typically extending much
3 further than 15m from the shore, a major portion of the pond surface is out of reach
4 of the apparatus as taught in McDowell, unless the pond is almost completely
5 dewatered or the apparatus is supported by a floating barge. Use of a floating barge
6 sufficient in size to accommodate the apparatus of McDowell may be impractical,
7 particularly for use in ponds where access is restricted such as in urban settings in
8 close proximity to residences, construction sites, landscaped terrains and other
9 types of access restrictions. McDowell does not disclose any sophisticated systems
10 which might permit programming remediation patterns or monitoring the location of
11 such apparatus relative to the pond surface and perimeter.

12 US Patent 4,911,831 to Davison et al teaches a self-propelled, floating
13 apparatus and land-based crane gantry for skimming sand from beds of slow sand
14 filters. An auger skimmer removes sand to a pre-determined depth and conveys
15 the sand to a pump for delivery to a remote location via a floating conduit. The
16 pump is located mid-point along the intake conduit away from the point of intake of
17 the sand/water slurry. The slurry has a preferred density of 20% w/w sand. Augur
18 depth is tracked and controlled however azimuthal location is not. Sonar, laser,
19 audio and camera sensors are employed to set and monitor dredging depth. The
20 apparatus of Davison et al is specifically designed for sand filter beds used in water
21 purification plants and requires that weeds be removed from each filter prior to

1 utilizing the sand skimmer. Cutters for removing weeds prior to suctioning the sand
2 may be incorporated.

3 A floating, mechanical clamshell and hydraulic dredge is disclosed in
4 US Patent 5,311,682 to Sturdivant. The dredge apparatus is fit with angular and
5 linear displacement sensors to permit geo-location for data logging and quality
6 assurance of work completed. Sturdivant is not shoreline based and must navigate
7 the pond to each site requiring remediation. Sediment is removed at near *in situ*
8 water content, as re-suspension due to water disturbance is minimized. High
9 density sediment is removed and conveyed at low speed and may require pre-pump
10 particle size reduction. A pipeline speed of 1 to 2 m/s compared to the prior art
11 speeds of 2 to 5 m/s for a slurry density of 0% to 30% are quoted. Dredging
12 operations may be tracked and optimized by electronically linking sensors on the
13 apparatus to a data processor such as a PC or a PLC. Sensors on the apparatus
14 may include GPS sensors.

15 An oil skimmer for use in remediation of oil spills is disclosed in
16 published PCT application WO 2012/027620 to Brown et al. A platform or vehicle
17 having an extendable arm is fit with a fluid skimmer for removing contaminants,
18 particularly oil, which are at or near the surface of contaminated bodies of water
19 such as rivers, lakes, marshes and the like. A pump on the skimmer collects
20 contaminants from the water surface and delivers same to a collection reservoir, via
21 a conduit. Alternatively, instead of a pump, a land based service apparatus

1 embodiment utilizes a boom connected directly to a vacuum truck for sucking water
2 and contaminants from the surface of the water.

3 Systems and methods for improving water quality in ponds is
4 described in Applicant's issued US Patent 8,333,895, with respect to Applicant's
5 NAUTILUS POND®. The described systems focus on enhancing sediment and/or
6 nutrient removal performance which are generally considered important functioning
7 components of a pond system. Typically, removal of sediment accumulations from
8 such ponds would require taking an entire pond offline for the duration of a
9 sediment removal operation.

10 Land-based pond remediation, as disclosed in the prior art, appears to
11 be limited largely by the reach of the equipment used, characteristics of the
12 sediment slurry or other remediation material targeted for removal and pond
13 operation. These limitations are exacerbated in developed areas due to additional
14 constraints imposed by architectural features, landscaping and legislative
15 considerations. Whereas these limitations may be overcome to some extent with
16 the use of an improvised assortment of currently available equipment or a floating
17 apparatus, the equipment is complex and adds constraints of transportation,
18 provision of access to pond and adapted waste conveyance structures.

19 Clearly there is interest in apparatus, methods and systems which
20 facilitate remediation of stormwater collection ponds efficiently and effectively and at
21 reduced cost compared to conventional systems currently in use. There is clearly a
22 need for effective and efficient apparatus for removal of matter from bodies of fluid

1 or reservoirs which is capable of extended reach into locations having limited or
2 restricted access and/or sensitive access.

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SUMMARY

5 Embodiments disclosed herein provide methods, systems and
6 apparatus for remediation of water bodies, the apparatus having an extended reach
7 compared to prior art apparatus, for use in ponds situated in urban, industrial and
8 remote areas. A multi-articulated boom is rotatably connected to a base which can
9 be a mobile base or a stationary structure. A slurry-capable pump, connected to the
10 distal end of the boom, is moved about the water body, such as a stormpond, by
11 rotation and manipulation of segments of the boom for suctioning sediment slurry
12 from the water body. The boom can be manipulated to reach over obstacles such
13 as houses, garages, landscaping positioned between the apparatus and the pond
14 permitting greater access to the pond thereby reducing the number of apparatus
15 required. In systems disclosed herein, the water body may have structured
16 platforms and accessways built therein to permit the apparatus to be deployed
17 within the perimeter of the water body thereby permitting even greater access to the
18 entirety of the water body for remediation operations. Geolocating apparatus
19 operatively connected to the boom and/or the pump permit monitoring of the
20 movements of the boom and pump enabling more efficient remediation with minimal
21 overlap particularly when the pond is full of water. Other attachments such as

1 blenders and fluid-addition jets permit controlling of the fluid properties of the slurry
2 removed by the pump.

3 Therefore in one broad aspect, apparatus for extended reach
4 remediation of a water body comprises a base and a multi-articulated, extendable
5 boom extending from a distal end to a proximal end and rotatably secured to the
6 base. A fluid conveyance conduit is secured to the extendable boom and extends
7 therealong between the distal end and proximal end of the boom. A slurry-capable
8 pump is supported at the distal end of the boom, the pump having a pump outlet
9 fluidly connected to a distal end of the fluid conveyance conduit. The pump receives
10 pumpable material at a pump intake and pumps the pumpable material through the
11 fluid conveyance conduit to a proximal discharge end of the conduit for discharge
12 therefrom.

13 The multi-articulated boom comprises a plurality of boom segments
14 which are hingedly connected therebetween. The length of the boom and the
15 maximum reach thereof is generally governed by the length of each of the plurality
16 of segments. The pump is lightweight so as to avoid loading a distal end of the
17 boom so much so that the apparatus becomes unstable. Outriggers, ballasting
18 strategies and buoyance devices can be used where heavier attachments to the
19 pump are used. Further, at least a distal segment of the boom can be reduced
20 somewhat in length to assist with overall stability of the apparatus without
21 compromising the effectiveness of the extended reach of the apparatus.

1 In another broad aspect, a system for remediation comprises an
2 extended reach apparatus having a base and a multi-articulated, extendable boom
3 having a distal end and a proximal end rotatably secured to the base. A fluid
4 conveyance conduit is secured to the extendable boom and extends therealong
5 between the distal end and the proximal end thereof. A slurry-capable pump is
6 supported at the distal end of the boom. The pump has a pump outlet fluidly
7 connected to a distal end of the fluid conveyance conduit, the pump receiving
8 pumpable material at a pump intake and pumping the pumpable material through
9 the fluid conveyance conduit to a proximal discharge end of the conduit for
10 discharge therefrom. A water body having a perimeter contains the pumpable
11 material therein for removal therefrom using the extended-reach apparatus.

12 The system further comprises platforms located within the perimeter of
13 the water body for locating the apparatus thereon to more effectively utilize the
14 extended reach of the apparatus for remediation of substantially the entirety of the
15 pond surface. Alternatively, the pond can be drained and the apparatus moved into
16 the pond perimeter. The apparatus is supported on the bottom of the pond or can
17 be supported on temporary supports such as swamp mats positioned therein.

18 In yet another broad aspect, a method for remediation of a water body
19 comprises locating an apparatus having a multi-articulated, extended-reach boom
20 for operatively supporting a slurry-capable pump at a distal end thereof at a
21 perimeter of the water body. The boom is manipulated for moving the slurry-capable
22 pump about the water body, the pump recovering pumpable materials therewith

1 from the pond. The pump pumps the pumpable materials to the perimeter of the
2 pond for removal therefrom.

3 Where the perimeter of the water body exceeds the reach of the multi-
4 articulated, extended reach boom, the method further comprises relocating the
5 apparatus to at least another location about or within the perimeter of the pond. The
6 steps of manipulating the boom for moving the pump and pumping the pumpable
7 materials are repeated.

8

9 BRIEF DESCRIPTION OF THE DRAWINGS

10 Figure 1A is a fanciful sketch illustrating a municipal pond undergoing
11 remediation according to the prior art using a plurality of backhoes employed in a
12 chain arrangement to shovel sediment from the pond for disposal;

13 Figure 1B is a plan view model of a stormpond according to the prior
14 art;

15 Figure 2 illustrates prior art remediation apparatus improvised so as to
16 extend the effective reach thereof, more particularly, a plurality of backhoe
17 machines located in a pond and supporting an extended conduit to reach a vacuum
18 truck located at a perimeter of the pond;

19 Figure 3A is a perspective view of an embodiment of an extended-
20 reach apparatus disclosed herein comprising a mobile base, a multi-articulated,
21 extendable boom rotatably connected thereto and a pump fit to a distal end of the
22 boom for suction and removal of pumpable materials from the pond;

1 Figure 3B is a fanciful sketch of the apparatus of Fig. 3A, illustrating
2 the capability of the boom to reach over obstacles positioned between the
3 apparatus and the pond and illustrating outriggers for stability of the apparatus
4 when the boom is extended;

5 Figure 4A is a partial sectional view of a progressing cavity (PC) pump
6 for use in embodiments described herein;

7 Figure 4B is a perspective view of the pump of Fig. 4A having geo-
8 locating apparatus operatively connected thereto;

9 Figure 4C is a perspective view of the pump of Fig. 4A having a
10 blender operatively connected to an intake of the pump;

11 Figure 4D is a perspective view of the pump of Fig. 4A with a partial
12 sectional view of a head having fluid-addition jets operatively connected to the
13 intake of the pump;

14 Figure 5 is a plan view of the stormpond of Fig. 1B, illustrating
15 constructed equipment platforms for supporting embodiments of apparatus
16 disclosed herein;

17 Figure 6 is a plan view of the stormponds of Figs. 1B and 5, illustrating
18 typical sedimentation areas adjacent inflow locations thereto;

19 Figure 7 is a fanciful sketch illustrating the comparative reach of
20 apparatus according to embodiments disclosed herein and prior art apparatus
21 shown in a portion of a water body having platforms and accessways therein;

1 Figure 8 is a plan view of a stormpond according to an embodiment
2 described herein having a network of equipment platforms and accessways within a
3 perimeter of the pond;

4 Figure 9 is a plan view of a NAUTILUS™ pond which are particularly
5 suitable for remediation according to embodiments taught herein, the sediment
6 depositing adjacent a perimeter thereof; and

7 Figure 10 is a plan view of the stormpond of Figs. 5 and 8 illustrating,
8 through circles imposed thereon about the equipment platforms, the effective reach
9 of remediation apparatus disclosed herein for remediation of substantially the
10 entirety of the pond area.

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DETAILED DESCRIPTION

13 Embodiments disclosed herein provide methods, systems and
14 apparatus for pond remediation, the apparatus having an extended reach compared
15 to prior art apparatus, for use in ponds situated in urban, industrial and remote
16 areas. The apparatus is capable of removing fluids and subsurface sediments and
17 slurry from bodies of fluid without resorting to prior art excavation or dredging
18 apparatus and techniques. Use of the terms “fluid”, “sediment” and “slurry” are used
19 interchangeably herein and are generally pumpable materials removable from the
20 pond using the apparatus described herein. In embodiments “pumpable” materials
21 are typically those which comprise water, solids such as sediment, silt and the like,
22 and possibly other components which are typically lighter than water, such as plant

1 matter, buoyant detritus and the like, and can be pumped by a pump, such as a
2 progressing cavity (PC) pump.

3 Although apparatus embodiments disclosed herein are described in
4 the context of land-based apparatus, apparatus can also be mounted on barge
5 platforms which are sized and structured to provide sufficient stability so as to
6 permit water-based remediations.

7 While suitable for use in a variety of constructed water bodies,
8 including storm water ponds and industrial waste water ponds, apparatus
9 embodiments are particularly suited for use in conjunction with NAUTILUS POND®,
10 as disclosed in Applicant's issued US Patent 8,333,895.

11 Embodiments disclosed herein provide systems for pond remediation
12 wherein pond configuration enables sediment to accumulate therein in a portion of
13 the pond, the sediment being removed therefrom as a liquidized slurry using
14 apparatus disclosed herein. Thickening of the liquidized materials on site may
15 further enable transport therefrom.

16

17 Prior Art

18 As is shown in Figs. 1A and 1B, a municipal pond 10, such as a storm
19 water pond, is often a desirable water feature, generally surrounded by residences
20 12. The proximity of such residences 12, or other landscape and recreational
21 features, limit access to the pond 10 by remediation equipment 14 and sediment
22 disposal carriers 15.

1 Remediation is often scheduled for off-season, such as in winter. The
2 conventional remedy to pond sedimentation may include draining the pond 10 in
3 order to provide access for excavating machines and conveyance vehicles 14 to
4 remove and dispose of excavated sediment. The pond 10 may be drained into the
5 municipal sewer system as drainage onto natural water ways during the winter
6 months may not be permitted.

7 As shown in Fig. 1A, a plurality of conventional backhoes 14,
8 equipped with excavation apparatus, are typically employed in a chain arrangement
9 to shovel sediment from a point in the pond 10, to a point closer to a shore or
10 perimeter and from there to a point on the perimeter for loading onto trucks 15.

11 As previously noted, the process can typically take 1 to 2 months for a
12 conventional storm water pond 10 and the cost can be in the order of about \$3M for
13 each remediation performed periodically, such as about once every 10 to 20 years
14 or so, on each pond 10. Disposal of drained water may be impractical due to
15 government regulations and permits. Operations are often undertaken in the winter.
16 Disposal of sediment is generally by spreading on other lands to dry or by
17 thickening using specialized slurry dewatering equipment.

18 Fig. 2 illustrates the problems which lead to a need for improvements
19 to conventional apparatus 14 and methods. Improvisation of conventional
20 equipment 14 has previously been required in the undertaking of pond remediation
21 or spill cleanup. In order to extend the reach of the prior art remediation equipment,
22 a vacuum truck 16 located at a distance from the point of removal, such as on

1 shore, is coupled to an intake pipe 18 through a conveyance hose 20. The hose 20
2 and intake pipe 18 require a plurality of spaced apart backhoe excavators 14
3 positioned in or about the water body or 10 or intermediate the vacuum truck 16 and
4 the water body 10 for support therealong. As one will appreciate, the means for
5 drawing up the sediment slurry or spilled fluids is located at a distal end of the hose
6 20 while the vacuum truck 16, connected to the proximal end of the hose 20,
7 provides lift for drawing the fluids into the intake pipe 18 and hose 20. The lift is
8 limited to the vacuum pressure which can be developed by the vacuum truck 16.
9 The amount of lift possible using this type of configuration may limit the
10 circumstances under which such an arrangement can be used, including those
11 situations where the source of the vacuum is positioned a great distance from the
12 intake pipe 18. Such systems are typically cumbersome, laborious and expensive
13 to implement in part due to the number of individual machines or components
14 involved and also due to the fact that each component is sub-optimal for the
15 purposes for which it is being used. Further, costs are increased due to the large
16 number of personnel required to operate each of the components.

17

18 Extended-reach embodiments

19 Concrete pump trucks are universally used and perceived as
20 mechanisms suitable for one thing only: the delivery of concrete.

21 Having reference to Figs. 3A and 3B, Applicant has recognized that a
22 multi-articulated boom 22 of the conventional concrete pumper truck, rotatably

1 connected to a base 24, would provide an apparatus 26 having an extended-reach,
2 pond surface access from a perimeter 28, suitable for most constructed water
3 ponds 10. Such is not the case with a conventional backhoe 14, since even a “long
4 stick” backhoe located on dry land would typically not be able to reach much more
5 than 15m from the water’s edge. The multi-articulated boom 22 typically comprises
6 a plurality of boom segments 30 hingedly connected therebetween.

7 As shown in Fig. 3B, segments 30 are controllably articulated, and
8 extended, as required, to extend the reach of the boom 22 vertically over obstacles
9 12, such as landscaping, houses or garages and the like, between the base 24 and
10 the pond 10, to reach into the pond 10 for removal of sediment therein. In
11 embodiments, the boom 22 is extendable from a location adjacent the base 24 to a
12 maximum reach of the boom when fully extended. As one of skill will appreciate, the
13 maximum reach of the boom 22 is a function of the number and length of the
14 segments 30 incorporated in the boom 22. In one embodiment disclosed herein, the
15 boom 22 has a maximum reach of about 50m or greater.

16 Applicant has determined there is typically no need for excavation-
17 enabling equipment at a distal end 32 of the multi-articulated boom 22, given many
18 subsurface pond sediments and other fine solids accumulations have a very
19 constant, pumpable, slurry-like consistency. Further, given the extremely long
20 moment arm of the multi-articulated boom 22, heavy appurtenances for mechanical
21 excavation at the distal end 32 would be a disadvantage.

1 In embodiments, as shown in Figs. 3A and 4A, a light-weight slurry-
2 capable pump 40 is supported at the distal end 32 of the multi-articulated boom 22
3 to suction and remove the pumpable slurry from the pond 10. A fluid conveyance
4 conduit 42 extends from the distal end 32 of the boom 22 to a proximal end 44 of
5 the boom 22, adjacent the base 24, and is supported along a length of the boom 22.
6 A pump discharge 46 is fluidly and operatively connected to a distal end 48 of the
7 conduit 42 for conveying the pumped slurry to a proximal discharge end 45 thereof
8 for discharge therefrom. The slurry pump 40 may hang by gravity from the distal
9 end 32 of the boom 22 having an intake end 50 positioned away from the distal end
10 32 of the boom 22. Alternatively, the pump 40 may be integrated into the boom
11 segment 30 at the distal end 32 with the intake end 50 of the pump 40 adjacent the
12 distal end 32 of the boom 22.

13 As those of skill in the art will appreciate, when the multi-articulated
14 boom 22 is extended, there is only a small tolerance for loading at the distal end 32
15 of the boom 22 without risk of tipping of the entire apparatus 26. Typically,
16 conventional multi-articulated booms, when loaded with concrete, are designed to
17 be able to withstand only a minimum loading at the boom's distal end 32, such as
18 an operator steering the boom 22 for delivery of concrete therefrom.

19 Thus, in embodiments, to maintain stability of the extended-reach
20 remediation apparatus 26, given the extended reach of the multi-articulated boom
21 22, Applicant believes the pump 40 must be sufficiently light-weight so as not to
22 generate any significant load on the distal end 32 of the boom 22, over and above

1 the pump's weight and that of the fluid being pumped. Thus, in embodiments, the
2 pump 40 and any attachments thereto, imparts only nominal forces at the boom's
3 distal end 32 so as to avoid threatening the stability of the apparatus 26. In
4 embodiments, the nominal load is about 100 lbs or less.

5 As shown in Fig. 3B, to counteract the potential instability of the
6 apparatus 26, as a result of extension of the boom 22 and pump 40 attached
7 thereto, the base 24 is typically provided with outriggers 52 which can be extended
8 and set for stabilizing the apparatus 26 during use.

9 Apparatus and methods of pond remediation herein disclosed
10 generally apply to removal of any fluid material having properties that one of skill in
11 the art could reasonably define as "pumpable", such as with a progressing cavity
12 (PC) pump, which may or may not be operated as a positive displacement pump.
13 Such fluid materials may include sand, silt and clay sediment slurry that
14 accumulates at a bottom of water bodies 10, such as storm water management
15 ponds.

16 Embodiments are discussed herein in the context of a PC pump 40,
17 however as one of skill will appreciate the pump 40 can be any similarly capable
18 pump technology. The PC pump 40 is capable of pumping the pumpable material
19 through the conveyance conduit 42 in the boom 22 with sufficient pressure such
20 that flexible or rigid extension pipes or conduit 54 attached to the proximal
21 discharge end 45 thereof may be used for transport of the pumpable material to a

1 local processing unit, to disposal, or to a truck/tanker loading area for remote
2 transport therein.

3 With reference again to Fig. 2, in the prior art, a spill remediation crew
4 uses a conventional backhoe 14 to place the intake pipe 18 of the vacuum hose 20
5 in a contaminated pool, pond or other water body 10. Vacuum to lift the
6 contaminated fluids is generated by the standard vacuum truck 16 to which the
7 hose 20 is connected. Such apparatus can typically only work if the required lift from
8 the fluid surface to the vacuum truck 16 tank is less than about 10m under ideal
9 conditions. Furthermore, it is difficult to control how water enters the intake pipe 18
10 as huge loads and changes in flow rate occur the instant the intake pipe 18 changes
11 from sucking air to sucking water.

12 By comparison, embodiments disclosed herein typically implement an
13 hydraulic drive on the PC pump 40, permitting generation of significant pumping
14 pressure, in addition to providing fine control over pumping flow rates, when
15 enabled as a variable speed drive. As one of skill will understand, the pump 40 can
16 be driven by an electric motor, pneumatics or any other power source that supports
17 the objective of driving the lightweight pump 40.

18 As discussed above, and as shown in Fig. 3B, the multi-articulated
19 boom 22 has sufficient reach such that it may be deployed over obstacles 12, such
20 as landscaping, homes, garages and the like positioned between the base 24 and
21 the pond 10, to access at least portions of the pond 10. If necessary, the multi-
22 articulated boom 22 and pump 40 can be wirelessly operated so that an operator

1 can be located in sight of the distal end 32 of the boom 22, rather than being
2 located solely at the base 24, enabling more precise control.

3 In embodiments, other optional attachments are mounted to the boom
4 22 or to the pump 40. As shown in Fig. 4B, one such optional attachment includes
5 geo-location apparatus 60, such as angle sensors, GPS and the like, linked to
6 computerized loggers and monitors (not shown) to provide monitoring, records and
7 quality assurance of work completed. A GPS 60 can be mounted at or adjacent the
8 pump 40 or the distal end 32 of the boom 22 for monitoring movement of the pump
9 40 about the water body 10. Further, angle sensors (not shown) on the boom
10 segments 30 and at the rotatable connection between the boom 22 and the base 24
11 aid in determining spatial positions of various boom components as well as the
12 intake end 50 of the pump 40 and may similarly be used for monitoring purposes.
13 Such geo-location apparatus 60 are particularly advantageous in un-drained ponds
14 10 where the remediation of subsurface sediment cannot easily be visually
15 inspected by the operator.

16 Optionally, as shown in Fig. 4C, a blender 62 for mechanically
17 chopping vegetation, detritus or other non-pumpable matter, is fit to the intake 50 of
18 the pump 40. The blender 62 may be of the contra-rotating or meshing blade type.
19 The blender 62 shreds weeds and otherwise non-pumpable material for rendering
20 such materials pumpable.

21 In an embodiment as shown in Fig. 4D, one or more fluid-addition jets
22 64 may also be fit at the pump intake 50 for control of slurry fluid properties or for

1 breaking up solid or semi-solid material into pumpable material. When activated,
2 fluid is directed from the addition jets toward the materials in the water body 10
3 adjacent the pump intake 50 to control slurry density or to form a slurry therefrom.
4 Control of fluid properties, such as slurry density, aids in facilitating remediation of
5 drier areas of the water body 10, such as sand bars and shores.

6 Other optional attachments include, but are not limited to, sensory
7 probes, spray nozzles, motion or still cameras and light duty, static or actuated
8 manipulators, grasping appurtenances or other custom designed attachments that
9 enable effective and/or efficient removal of slurry according to the general or
10 localized slurry's material properties. Further, combinations of attachments are
11 contemplated, such as combining fluid-addition jets with a blender.

12 Large, heavy or unwieldy attachments that cannot safely be supported
13 entirely by the fully extended multi-articulated boom 22 may be launched into the
14 water body 10 and be manipulated by the boom 22, or attachments thereto, into the
15 desired operating area.

16 One such example is a bottom skimmer attachment (not shown)
17 operatively and fluidly connected to the pump intake 50, such as by a flexible hose.
18 Such apparatus is generally too heavy to be supported above the water surface at
19 the distal end of the boom 22 when the boom 22 is fully extended. The skimmer can
20 however be initially deployed into the water body 10 in a stable configuration with
21 the boom 22 only partially extended until the skimmer is supported substantially by
22 the bottom of the water body 10. Thereafter, the skimmer is enabled to be gently

1 dragged about the water body 10 using the boom 22 in the fully extended position
2 without affecting the stability of the apparatus 26.

3 Alternatively, where heavy attachments intended for underwater
4 operation are to be connected to the distal end 32 of the boom 22, unsafe boom
5 loading forces can be significantly reduced, effectively minimized or eliminated
6 entirely through buoyancy compensation strategies.

7 Alternatively, in embodiments, adjustments to the length of at least
8 one or more of the boom segments 30 enables safe and stable operation of the
9 apparatus 26 with the boom 22 fully extended. For example, the segment 30 at the
10 distal end 32 of the boom 22 can be shortened, such as by a few metres, to reduce
11 the weight of the distal end of the boom 22 for accommodating heavier attachments
12 to be connected thereto without upsetting the stability of the apparatus.

13 Further, in embodiments, the apparatus 26 has a distal segment 30
14 which is configured to receive a variety of specially designed attachments which
15 have an attachment length appropriate for the relative weight of the attachment so
16 as not to challenge the stability of the apparatus 26 when the boom 22 is fully
17 extended.

18 The utility of the extended-reach apparatus 26 extends to ecologically-
19 sensitive areas, dams, access over embankments, roadside areas, vicinity of
20 forestry roads and impassable areas. The extended-reach apparatus 26 may also
21 be used to remediate spills.

1 Additional embodiments are focused on extreme mobility, such as
2 may be the case when remediating remote, spill-contaminated water bodies 10
3 accessible by helicopter or other means of remote transport. The extended-reach
4 apparatus 26 may comprise a lightweight multi-articulated boom 22 mounted on a
5 high-maneuverability trailer or other form of mobile base 24, or may comprise on-
6 site assembled apparatus 26 for assembly onto an *in situ* stationary support or base
7 24 from highly mobile components. The mobile components include the lightweight
8 multi-articulated boom 22 and the pump 40 for mounting at the distal end 32 of the
9 boom 22. The boom 22 is rotatably mounted to the *in situ* base 24 and provided the
10 required functionality, but without the base 24 being mobile. Outrigger arms 52 of
11 such a modular apparatus 26 could be attached to anchors embedded in the *in situ*
12 base 24. Alternatively, ballast normally provided by the inherent mass of the mobile
13 vehicle base 24 is added to each outrigger arm 52 in the form of either one or more
14 massive objects or reservoirs filled with water, or some combination of ballasting
15 strategies.

16 Thus, as one can see from the previous description, in embodiments,
17 the base 24, to which the multi-articulated boom 22 is connected, can be mobile
18 base 24, such as a self-propelled vehicle, a trailer for transport to a desired site or
19 an *in situ* stationary support base 24 on which the apparatus 26, including at least
20 the boom 22 and pump 40, can be assembled.

21

22

1 Pond remediation systems

2 While those of skill in the art will appreciate, there are a wide variety of
3 scenarios in which embodiments disclosed herein could be applied, embodiments
4 are described in the context of constructed water bodies 10. Such constructed water
5 bodies 10 include storm water ponds, industrial process water ponds, tailings ponds
6 such as are used in mining, oilsands and a variety of other industrial processes and
7 the like.

8 Having reference again to Figs. 3A and 3B, in an embodiment, the
9 base 24 is a mobile base suitable for successive relocation along the pond
10 shoreline or perimeter 28. The mobile base 24 is provided in the form of a vehicle,
11 such as a conventional, self-propelled concrete pumper-truck, rotatably supporting
12 the multi-articulated boom 22. The slurry-capable pump 40, such as the
13 progressing cavity-type (PC pump) or similar, as shown in Figs. 4A-4D, is secured
14 to the distal end 32 of the multi-articulated, extendable boom 22 and is fluidly and
15 operatively connected to the fluid conveyance conduit 42. In effect, the concrete
16 pumper is thus modified to operate in reverse of its normal operation to pump slurry
17 through the conduit 42 from the distal end 32 of the multi-articulated, extendable
18 boom 22 instead of delivering concrete to the distal end 32. The boom 22 is typically
19 rotated, in operation, to a position which is off-set to the direction of travel of the
20 mobile base 2 for increased stability. In embodiments, the conventional concrete
21 slurry pump is removed from the pumper-truck.

1 Alternatively, the conventional concrete slurry pump, or additional
2 slurry-capable pumps are used to boost the slurry pressure in the conveyance
3 conduit 42 if the pump 40 is unable to generate sufficient pressure to discharge the
4 slurry therefrom particularly if the slurry is being delivered to a location remote from
5 the apparatus 26.

6 As will be appreciated, an advantage of embodiments taught herein is
7 reduced cost as individual components of the extended-reach apparatus 26 are
8 mature products already on the market which can be readily retrofit as described
9 above or otherwise modified for assembly. Alternatively, whilst the extended-reach
10 apparatus 26 can advantageously be constructed by modification of existing
11 equipment, a purpose-built apparatus 26 can also be constructed atop a
12 transportable platform or self-propelled vehicle 24.

13 Having reference to Fig. 5, prior art stormponds such as shown in Fig.
14 1B, may be retrofit with platforms 70 onto which embodiments of the extended-
15 reach remediation apparatus 26 disclosed herein can be positioned or assembled
16 during remediation, particularly when the pond 10 contains water. Such platforms
17 70 can be positioned within the pond's external boundaries or perimeter 28. In this
18 way the platforms 70 act to extend the effective reach of the multi-articulated booms
19 22. Accessways 72 are provided for driving the mobile base 24 thereonto.
20 Alternatively, the platforms 70 are otherwise able to receive and support the
21 apparatus 26 thereon. The number of platforms 70 and deployments of the
22 apparatus 26 required to reach the entire pond surface is minimized by functionally

1 and strategically expanding the pond perimeter 28 throughout the pond footprint.
2 Accessways 72 and/or platforms 70 may or may not be dry when the water body 10
3 is at a normal water level. The platforms 70 and/or accessways 72 thereto can be
4 constructed and dressed, such as with picnic tables and other features, so as to act
5 as public amenities when dry and when not in use for pond remediation.

6 As shown in Fig. 6, in prior art ponds 10, sediment S, shown in circles
7 D superimposed onto the pond surface, is deposited at areas of major and minor
8 inflow M,m to the pond 10. The sediment deposits D may require remediation to a
9 diameter of 100m or greater at areas of major inflow M and to a diameter about 50m
10 or greater at areas of minor inflow m thereto.

11 Having reference to Fig. 7, it is clear that even when the water body
12 10 is configured to have constructed equipment accessways 72 and equipment
13 platforms 70, unlike the apparatus 26 taught herein, a conventional "long stick"
14 backhoe 14 positioned thereon and having an effective reach of about 25m would
15 not be able to effectively remediate the pond 10.

16 Having reference to Figs. 5, 7 and 8, platforms 70 may or may not be
17 interconnected by a network of accessways 72, where the accessways 72 may be
18 used to enable vehicular and/or public access, provide localized pond cell
19 containment or other desired functions. Accessways 72 may also serve aesthetic or
20 functional purposes in the context of providing a physical element that can be used
21 to grow and develop aquatic and/or riparian ecosystems supporting plant

1 communities. As shown in Fig. 5, a peninsula 76 may be formed where an
2 accessway 72 connects an equipment platform 70 to the shore 28.

3 Alternatively, in the case where the pond 10 is drained prior to
4 remediation, embodiments of the mobile, extended-reach apparatus 26 can be
5 deployed strategically within the pond perimeter 28 to permit access to substantially
6 the entirety of the pond footprint. Temporary structures such as swamp mats or
7 gravel road beds (not shown) can be used to support the apparatus 26 when driven
8 into the drained pond 10. Alternatively, the base of the pond 10 may be constructed
9 in such a manner as to provide a stable base to support the apparatus 26 for
10 remediation from within the pond perimeter 28.

11 Having reference again to Fig. 3A, in embodiments, the extension
12 conduit 54 is fluidly connected to the discharge end 45 of the slurry conveyance
13 conduit 42 to deliver the pumped slurry to disposal carriers positioned adjacent the
14 base 24 or the platform 70 or stationed some distance away.

15 Alternatively, as shown in Fig. 5, the extension conduit 54 can deliver
16 pumped slurry to other desired destinations, such as local processing or disposal
17 facilities 80. In this way, pond sediment slurry, extracted by the extended-reach
18 apparatus 26, can be conveyed from the pond 10 to locations spaced away from the
19 pond 10, such as to trucks 15 stationed along roads 82 which may not have direct
20 access to the pond 10, but which typically encircle the pond 10 in urban areas.
21 Residences 12 are typically located adjacent the road 82, sandwiched between the
22 road 82 and pond 10. While the extended-reach apparatus 26 can typically be

1 deployed adjacent the pond 10 through a provided, pond access 84, discharge of
2 sediments are not so restricted. The extension conduit 54, connected to the
3 conveyance conduit 42 can be deployable between residences 12 or other non-
4 vehicle accessways.

5 As one of skill will appreciate, local processing facilities 80, whether
6 permanent or mobile, can be used. Such facilities 80 can, for example, permit
7 significant dewatering of the recovered slurry, reducing the volume and thus the
8 cost of transporting material to another location. The drier material is also more
9 conveniently transported. Alternatively, dewatered slurry may be useful onsite in the
10 construction of retrofit berms, equipment platforms within the pond perimeter, and
11 the like. Where available, recovered slurry may be pumped to a local storage area
12 for temporary or permanent disposal.

13

14 Pond Remediation Methods

15 In accordance with the embodiments of the extended-reach
16 apparatus 26, methods for pond sediment remediation described herein are
17 enabled.

18 As one of skill will understand, using embodiments of the apparatus
19 26 taught herein, remediation methods can be performed regardless whether the
20 pond 10 is drained or not, or at what level the pond 10 is filled. Applicant believes
21 that the extended-reach apparatus 26 is capable of removing high density
22 pumpable sediment when the PC pump 40 is used. One such pumpable slurry

1 comprises about 40% w/w solids. Further, the pump 40 is capable of removing
2 materials from the water body 10 which are lighter than the water therein. Thus, any
3 pumpable slurry formed of high density sediment and low density materials can be
4 removed. In drained situations, or where pond levels are very low, advantageously
5 the burden on waste disposal in downstream processing is reduced as the amount
6 of water incorporated in the slurry is significantly reduced.

7 In embodiments, as shown in Figs. 3B, 5, 7 and 8, to remediate a
8 water body 10, an embodiment of the extended-reach apparatus 26 is driven or
9 otherwise located onto the perimeter or shoreline 28 thereof or onto a platform 70
10 located within the perimeter 28. The extended-reach apparatus 26 is positioned in a
11 stable attitude, generally with outriggers 50 deployed to counter moment loads,
12 such as depicted in Fig. 3B. The extendable multi-articulated boom 22 is extended
13 over the water surface with the pump 40 positioned over an area of sediment or
14 other materials to be removed. The position of the pump 40 is geo-located if
15 embodiments comprising geo-location equipment 60 are being used.

16 Upon operation of the boom 22 and the pump 40, sediment and
17 associated matter is pumped from the pond 10 and conveyed, via the slurry
18 conveyance conduit 42 and extension 54 thereto, to disposal trucks 15 that may be
19 stationed some distance away or to local processing facilities 80 or other desired
20 locations. Through extension, retraction and rotation operations of the extendable,
21 articulated boom 22, the slurry-capable pump 40 can be successively relocated
22 about the pond 10 to the extent of the extended-reach boom 22, such as in a

1 controlled pattern, to reduce remediation overlap and maximize efficiency.
2 Minimum load is required to manipulate the pump 40 to each new location, the
3 material through which the pump 40 is moved being of a slurry-like consistency.

4 Where the geo-location equipment 60 is used, location data indicative
5 of remediation patterns can be logged and saved to a computer for record keeping
6 and quality assurance reporting. Other electronic records may be made using
7 conventional recording equipment such as cameras, depth monitors and other
8 sensors, to further assist with management of the remediation.

9 If the size of the pond 10 is sufficiently large, after an operation to
10 remove sediment from one portion of the pond 10, to the maximum practical reach
11 of the extendable multi-articulated boom 22 is completed, the apparatus 26 is
12 relocated to another location on the perimeter 28 or platform 70 located within the
13 pond perimeter and the operation is repeated.

14 As shown in Fig. 9, a particular pond configuration known as a
15 NAUTILUS POND® which is described in detail in Applicant's corresponding US
16 patent 8,333,895, has a tangential inlet 100, a central outlet 102 and a generally
17 peripheral vortex-flow for preferential deposition of sediment S about the perimeter
18 28 of the pond 10. The predominantly peripheral sedimentation patterns S are
19 particularly well suited for remediation using the embodiments described herein.

20 In the case where the pond 10 has been drained, the extended-reach
21 apparatus 26 can be relocated to temporary structures or roadways formed in the

1 pond 10 or simply to a desired location of the bed of the pond 10, if so constructed
2 to support the apparatus 26, and the operation as described is repeated.

3 Fig. 10 illustrates through circles superimposed on the pond footprint,
4 each having a radius of about 50m, most, if not all, of the water body footprint area
5 is accessible by the embodiments of extended-reach apparatus 26 taught herein,
6 particularly when situated on strategically located equipment platforms 70 within the
7 pond perimeter 28.

8 In embodiments, the platforms 70 are sized about 12m x about 15m.
9 As one of skill in the art will realize, the size of platforms 70 is illustrative only. The
10 platforms 70 will vary in size depending on a number of factors, including the kind
11 and size of the base 24 used, site access restrictions, site specific boom-reach
12 requirements or other factors to be considered on a project by project basis.

13

1 **THE EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR**
2 **PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:**
3

4 1. Apparatus for extended reach remediation of a water body
5 comprising:

6 a base;

7 a multi-articulated, extendable boom extending from a distal end to a
8 proximal end rotatably secured to the base;

9 a fluid conveyance conduit secured to the extendable boom and
10 extending therealong between the distal end and proximal end of the boom; and

11 a slurry-capable pump supported at the distal end of the boom, the
12 pump having a pump outlet fluidly connected to a distal end of the fluid conveyance
13 conduit, the pump receiving pumpable material at a pump intake and pumping the
14 pumpable material through the fluid conveyance conduit to a proximal discharge
15 end of the conduit for discharge therefrom.

16

17 2. The apparatus of claim 1 wherein the multi-articulated boom
18 comprises a plurality of boom segments hingedly connected therebetween, a
19 maximum reach of a distal end of the boom being determined by a length of each of
20 the plurality of segments.

21

22

1 3. The apparatus of claim 1 or 2 wherein the slurry-capable pump
2 imposes a nominal load on the distal end of the boom, when extended from the
3 base, for maintaining stability of the apparatus.

4

5 4. The apparatus of claim 1, 2 or 3 wherein the slurry-capable
6 pump is a progressing cavity type pump.

7

8 5. The apparatus of any one of claims 1 to 4 further comprising;
9 geo-locating equipment operatively connected to the pump for
10 positioning the pump intake to minimize remediation overlap and maximize
11 efficiency.

12

13 6. The apparatus of any one of claims 1 to 5 further comprising
14 outriggers operatively connected to the base for stability thereof when deployed
15 therefrom.

16

17 7. The apparatus of any one of claims 1 to 6 further comprising:
18 a blender operatively and fluidly connected to the pump intake for
19 rendering non-pumpable materials pumpable therethrough.

20

21

1 8. The apparatus of any one of claims 1 to 6 further comprising:
2 one or more fluid-addition jets operatively connected to the pump
3 intake for controlling at least a density of the slurry at the pump intake.

4

5 9. The apparatus of claim 8 wherein the fluid from the one or more
6 fluid-addition jets forms the slurry with solid or semi-solid materials in the water
7 body.

8

9 10. A system for remediation comprising:
10 an extended reach apparatus having
11 a base;
12 a multi-articulated, extendable boom having a distal end and a
13 proximal end rotatably secured to the base;
14 a fluid conveyance conduit secured to the extendable boom
15 and extending therealong between the distal end and the proximal end
16 thereof; and
17 a slurry-capable pump supported at the distal end of the boom
18 the pump having a pump outlet fluidly connected to a distal end of the fluid
19 conveyance conduit, the pump receiving pumpable material at a pump intake
20 and pumping the pumpable material through the fluid conveyance conduit to
21 a proximal discharge end of the conduit for discharge therefrom; and

1 a water body having a perimeter and containing the pumpable
2 material therein for removal therefrom using the extended-reach apparatus.

3

4 11. The system of claim 10 wherein the perimeter supports the
5 extended reach apparatus thereon.

6

7 12. The system of claim 10 or 11 wherein the water body further
8 comprises:

9 one or more platforms located within the perimeter of the water body
10 for supporting the extended reach apparatus thereon, the one or more platforms
11 being connected to the perimeter for access thereto.

12

13 13. The system of any one of claims 10 to 12 further comprising a
14 stable bottom of the water body for supporting the extended reach apparatus
15 thereon when the water body is drained.

16

17 14. The system of any one of claims 10 to 13 further comprising
18 temporary structures located on the bottom of the water body for supporting the
19 extended reach apparatus thereon.

20

21 15. The system of any one of claims 10 to 14 wherein the base is a
22 mobile base.

1 16. The system of any one of claims 10 to 14 wherein the base is a
2 stationary base located about or within the perimeter of the water body; and
3 the multi-articulated, extendable boom, the fluid conveyance conduit
4 and the slurry-capable pump are modular components for assembling on the
5 stationary base for forming the extended-reach apparatus.

6
7 17. The system of any one of claims 10 to 16 wherein the water
8 body is a NAUTILUS POND®, having a tangential inlet, a central outlet and a
9 generally peripheral vortex-flow for preferential deposition of sediment about a
10 perimeter of the pond.

11
12 18. The system of any one of claims 10 to 17 further comprising
13 onsite processing facilities for receiving the pumpable materials from the fluid
14 conveyance conduit at least for dewatering thereof.

15
16 19. A method for remediation of a water body comprising:
17 locating an apparatus having a multi-articulated, extended-reach
18 boom for operatively supporting a slurry-capable pump at a distal end thereof at a
19 perimeter of the water body;
20 manipulating the boom for moving the slurry-capable pump about the
21 water body, the pump recovering pumpable materials therewith from the pond; and

1 pumping the pumpable materials from the pump to the perimeter of
2 the pond for removal therefrom.

3

4 20. The method of claim 19 wherein the perimeter of the water
5 body exceeds the reach of the multi-articulated, extended reach boom, the method
6 further comprising;

7 relocating the apparatus to at least another location about or within the
8 perimeter of the pond; and

9 repeating the steps of manipulating the boom for moving the pump
10 and pumping the pumpable materials.

11

12 21. The method of claim 19 or 20 wherein the manipulating the
13 boom further comprises:

14 manipulating the boom for moving the slurry pump in a pattern for
15 minimizing overlap of remediation of the water body.

16

17 22. The method of claim 19, 20 or 21 further comprising:

18 monitoring the movement of the slurry pump about the water body for
19 mapping the movement for minimizing overlap of remediation of the water body.

20

21

1 23. The method of any one of claims 19 to 22 further comprising:
2 mechanically blending non-pumpable materials in the water body for
3 rendering the non-pumpable materials pumpable.

4

5 24. The method of any one of claims 19 to 23 further comprising:
6 controlling fluid properties of the pumpable materials using one or
7 more fluid-addition jets operatively connected to an intake of the pump for rendering
8 the non-pumpable materials pumpable.

9

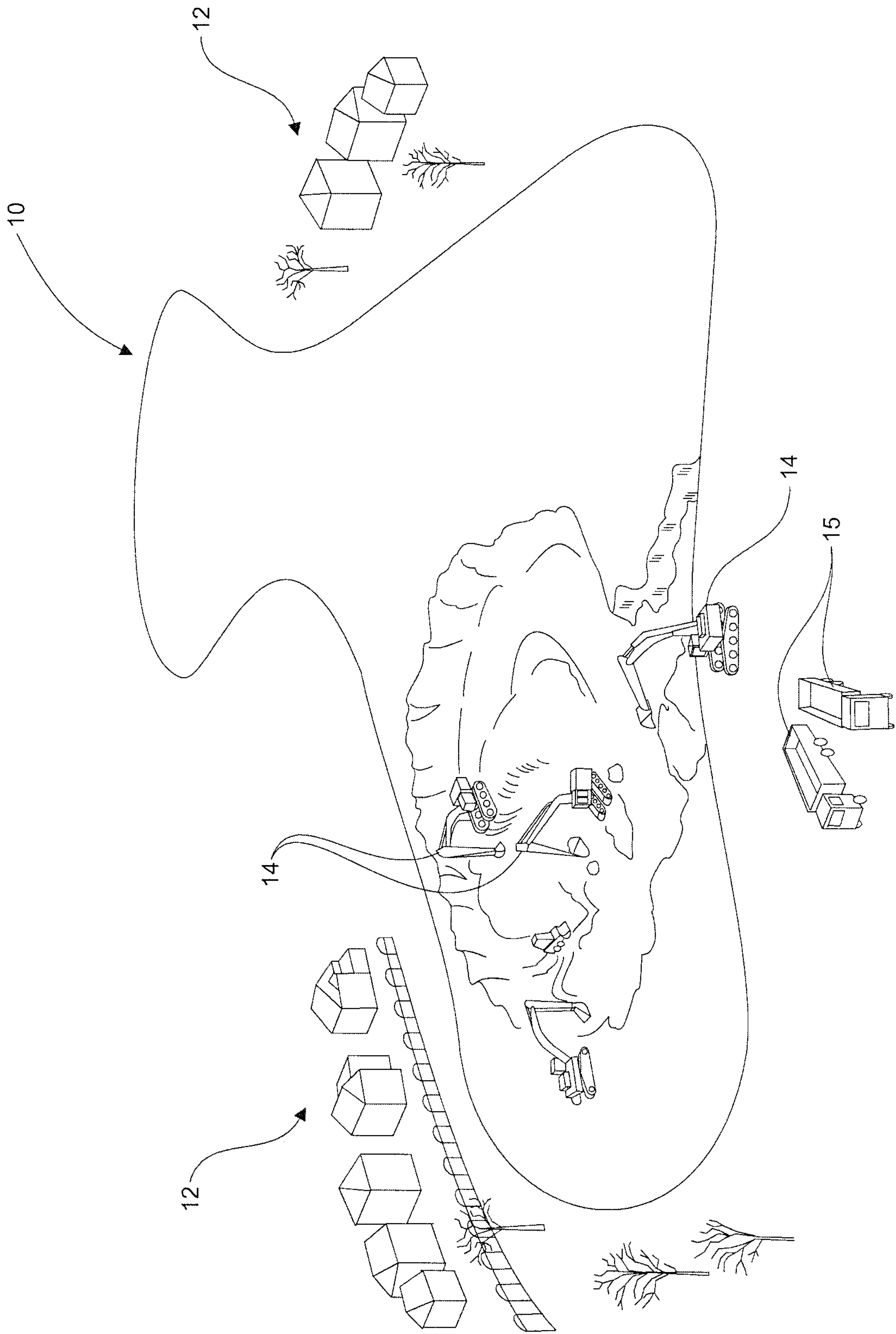


Fig. 1A
PRIOR ART

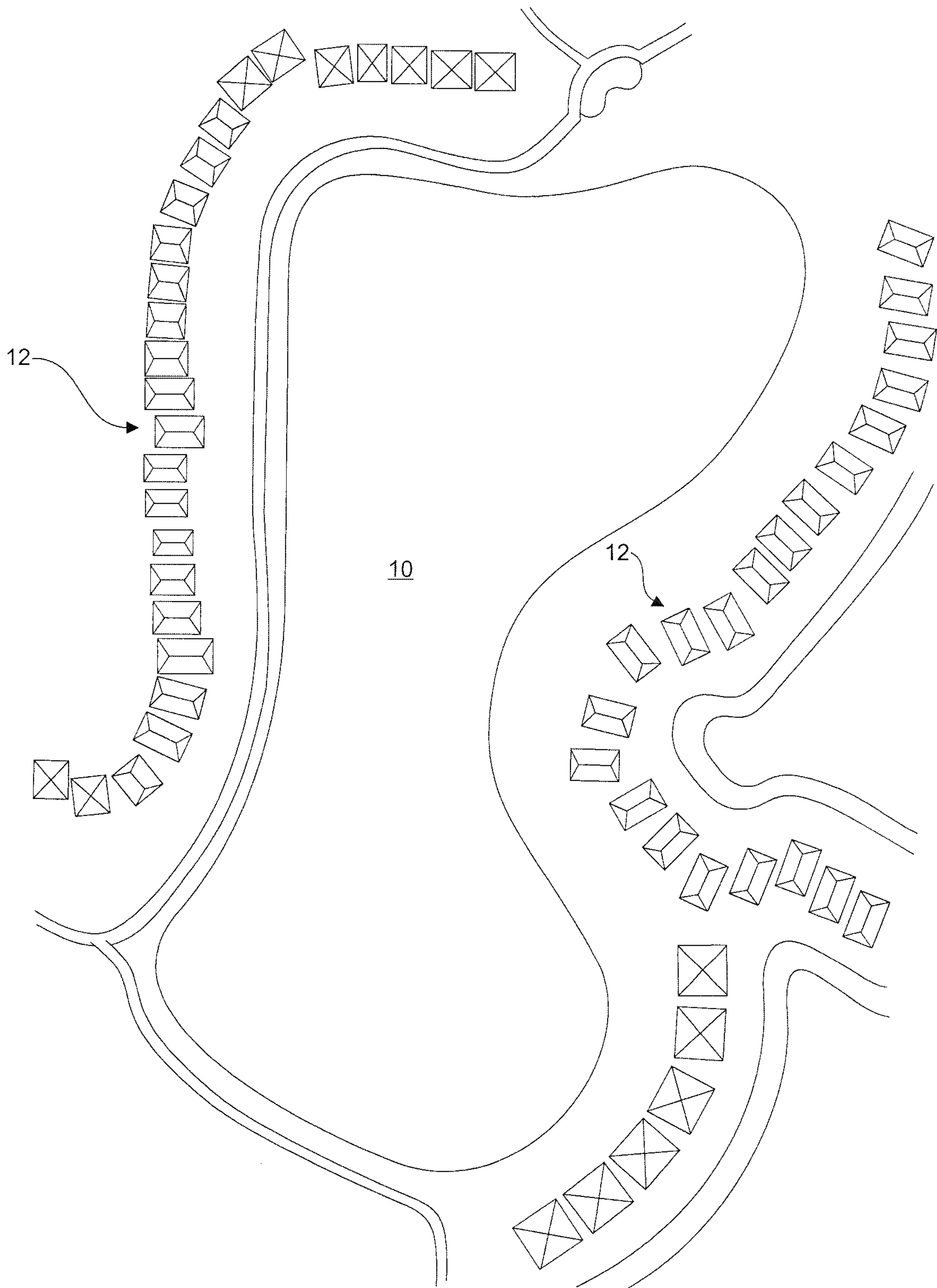


Fig. 1B
PRIOR ART

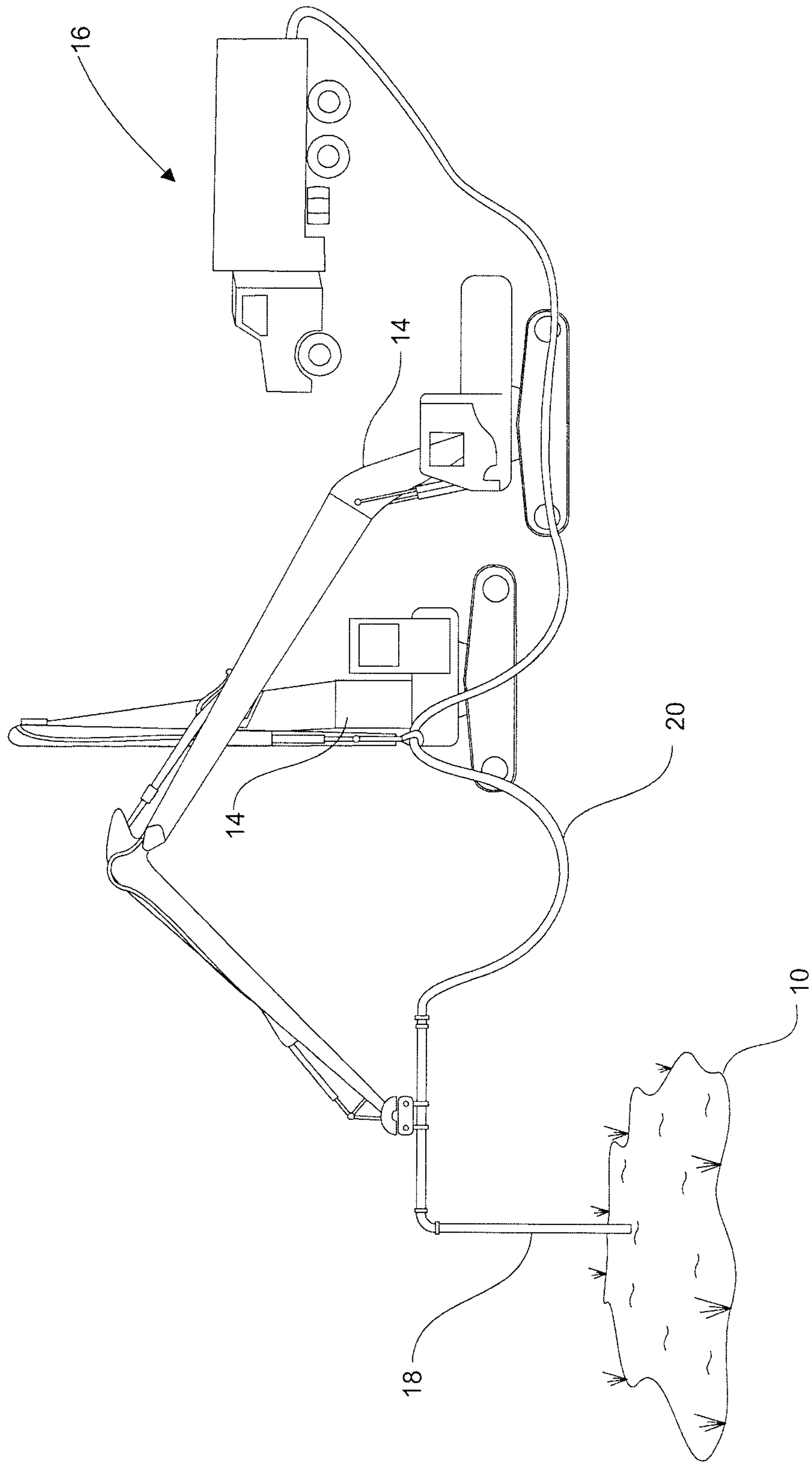


Fig. 2
PRIOR ART

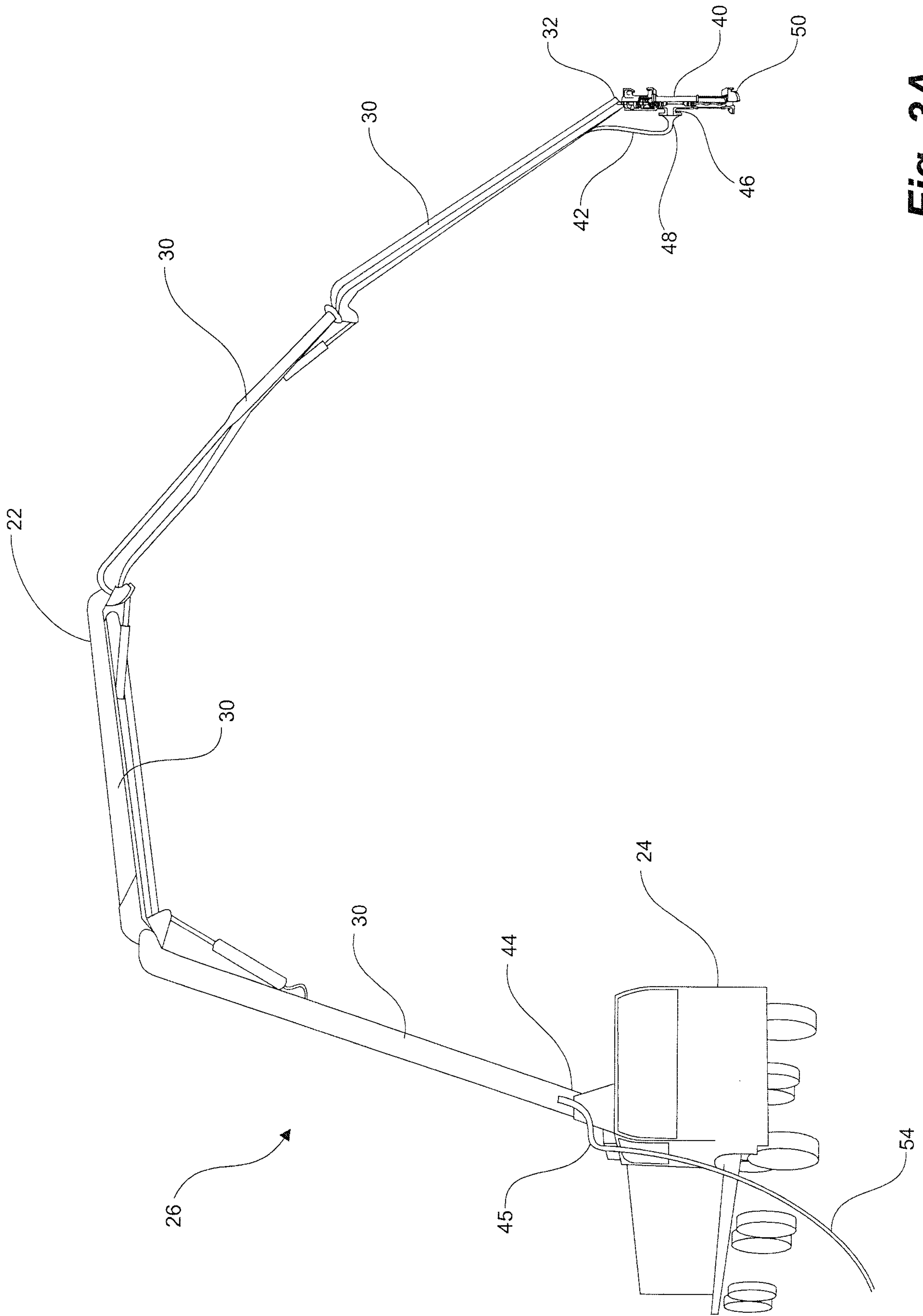


Fig. 3A

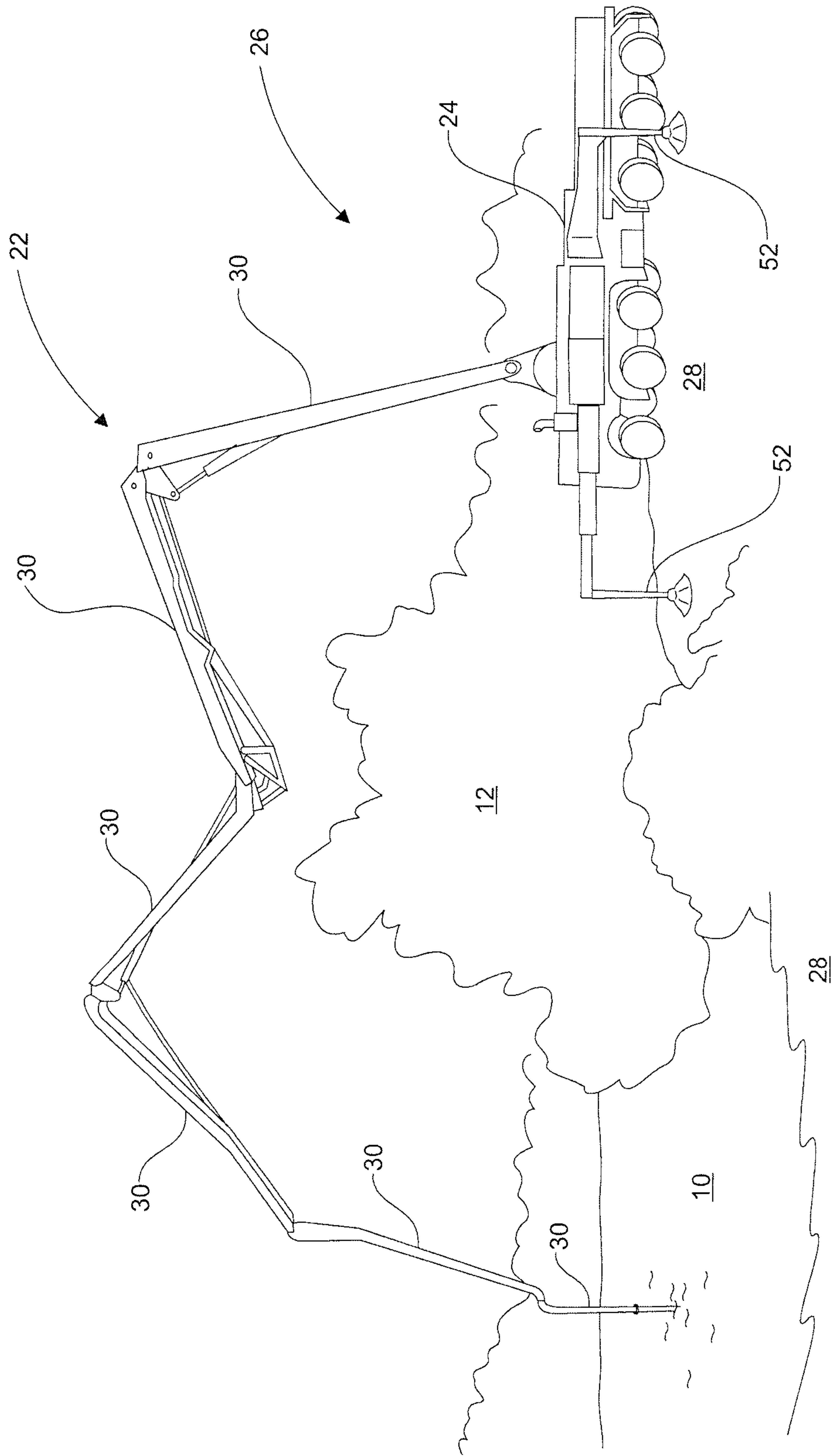


Fig. 3B

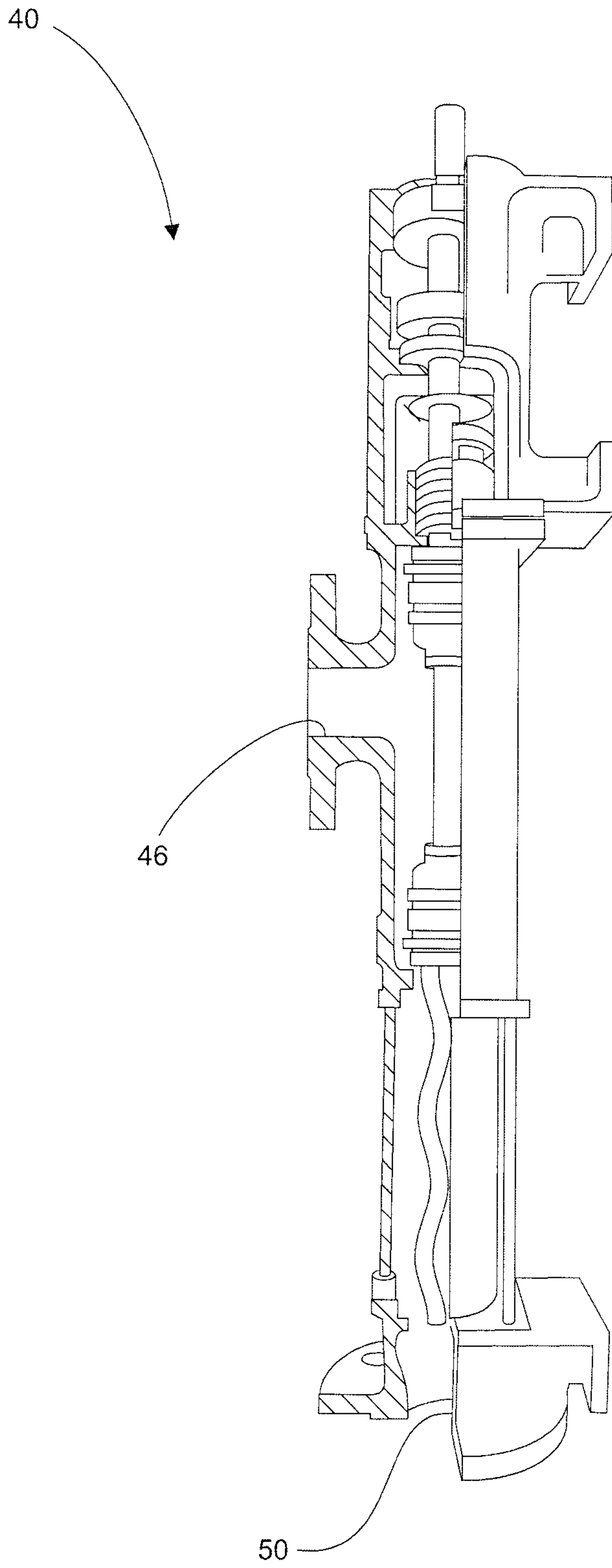


Fig. 4A

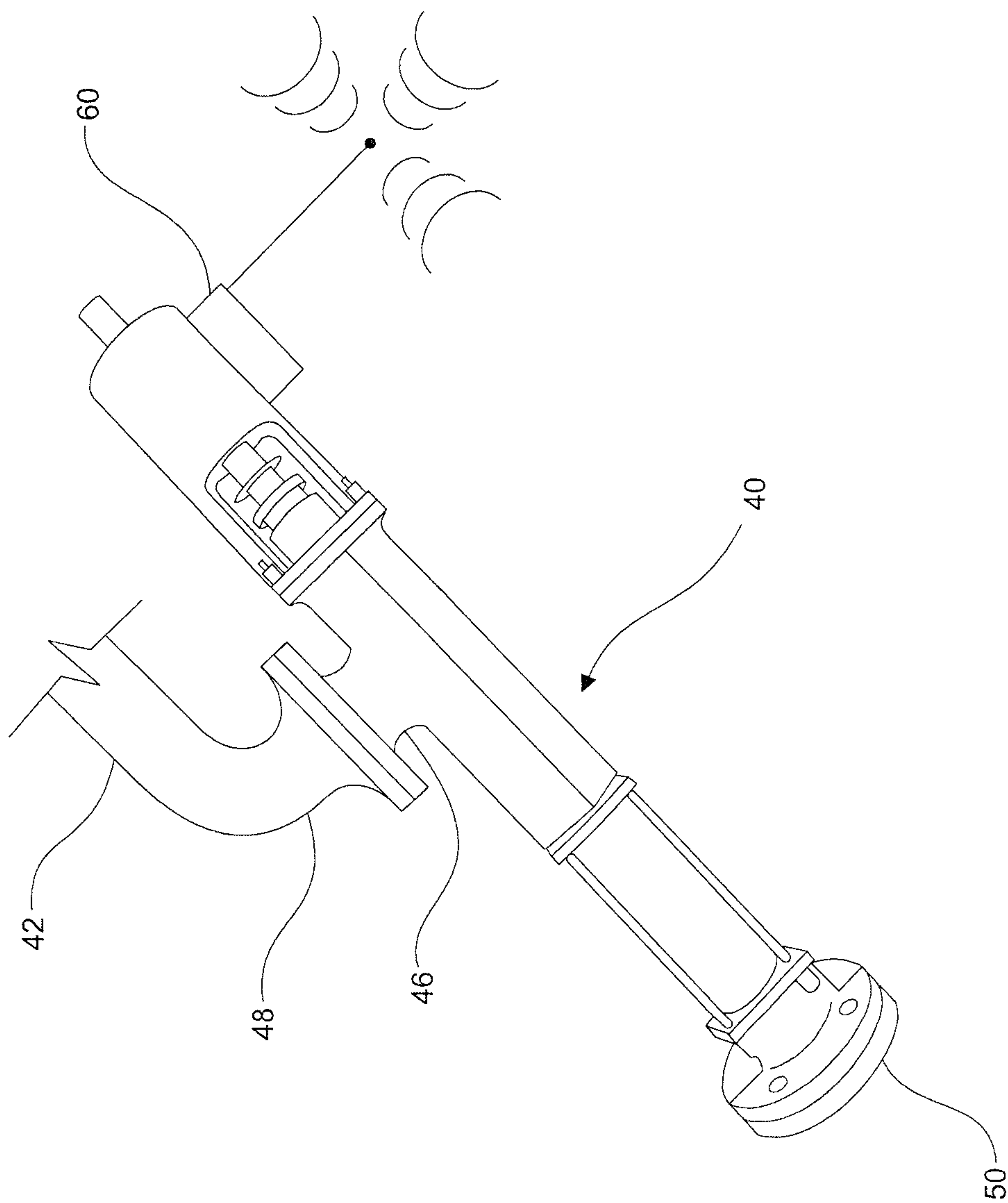


Fig. 4B

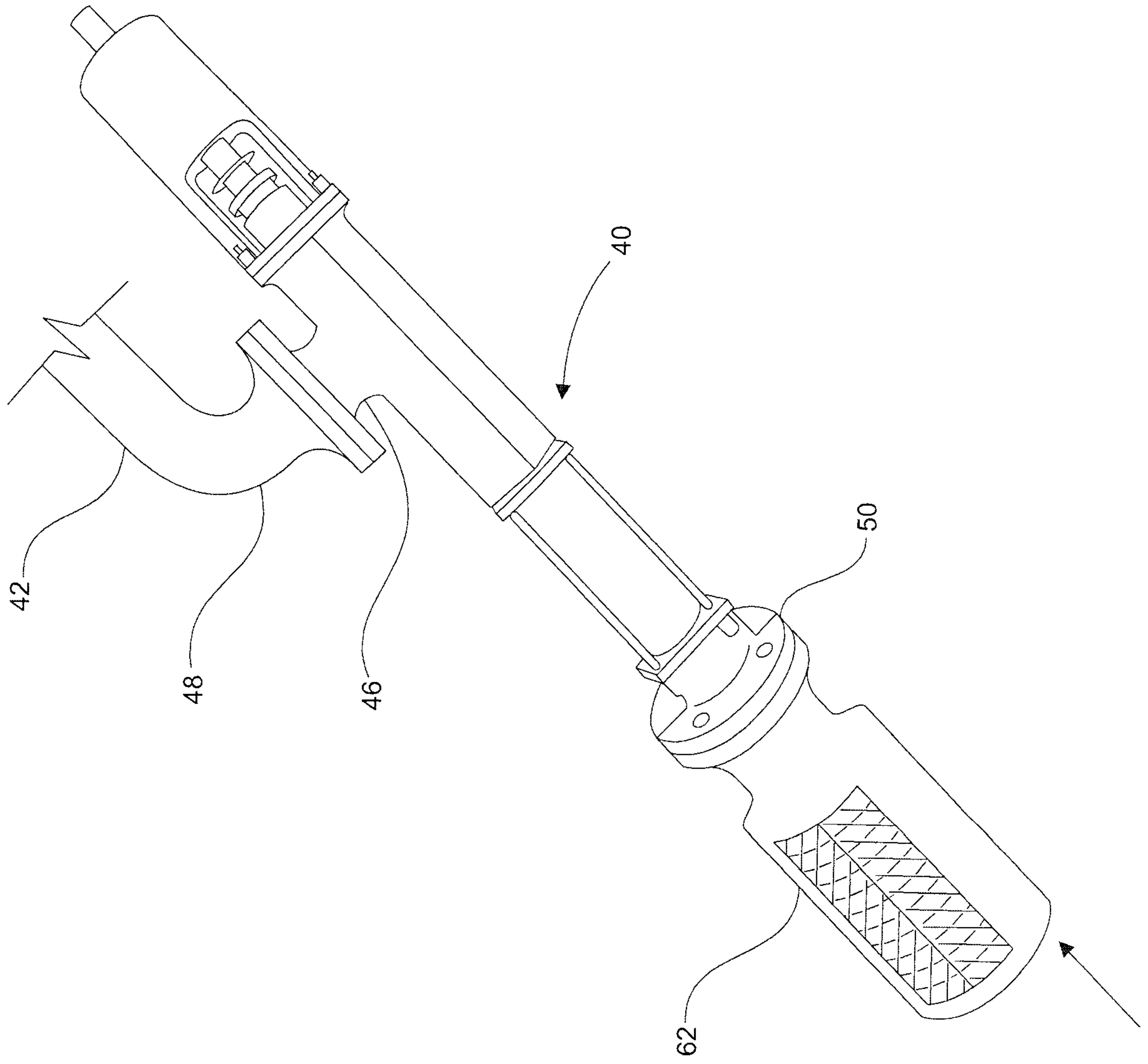


Fig. 4C

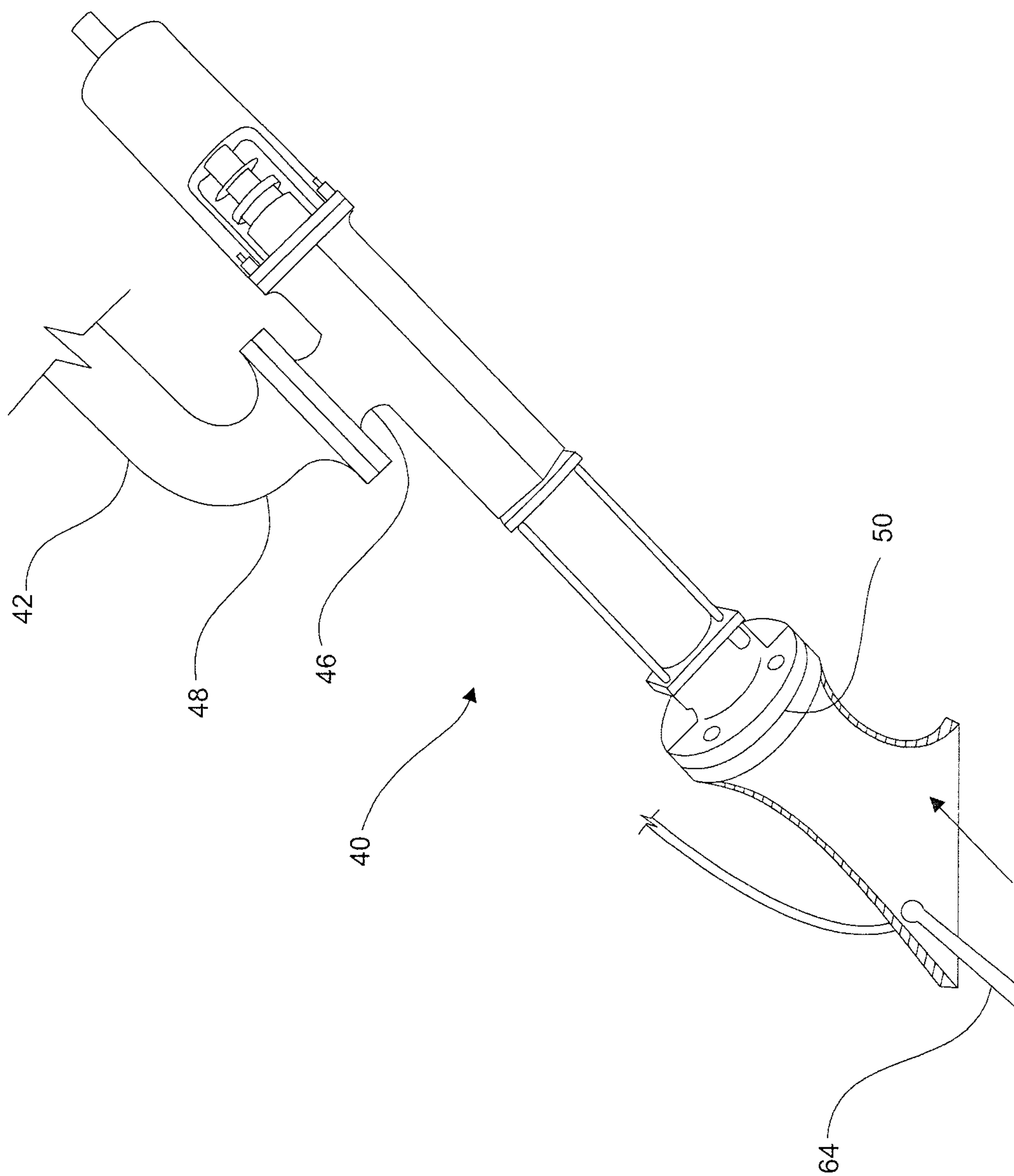


Fig. 4D

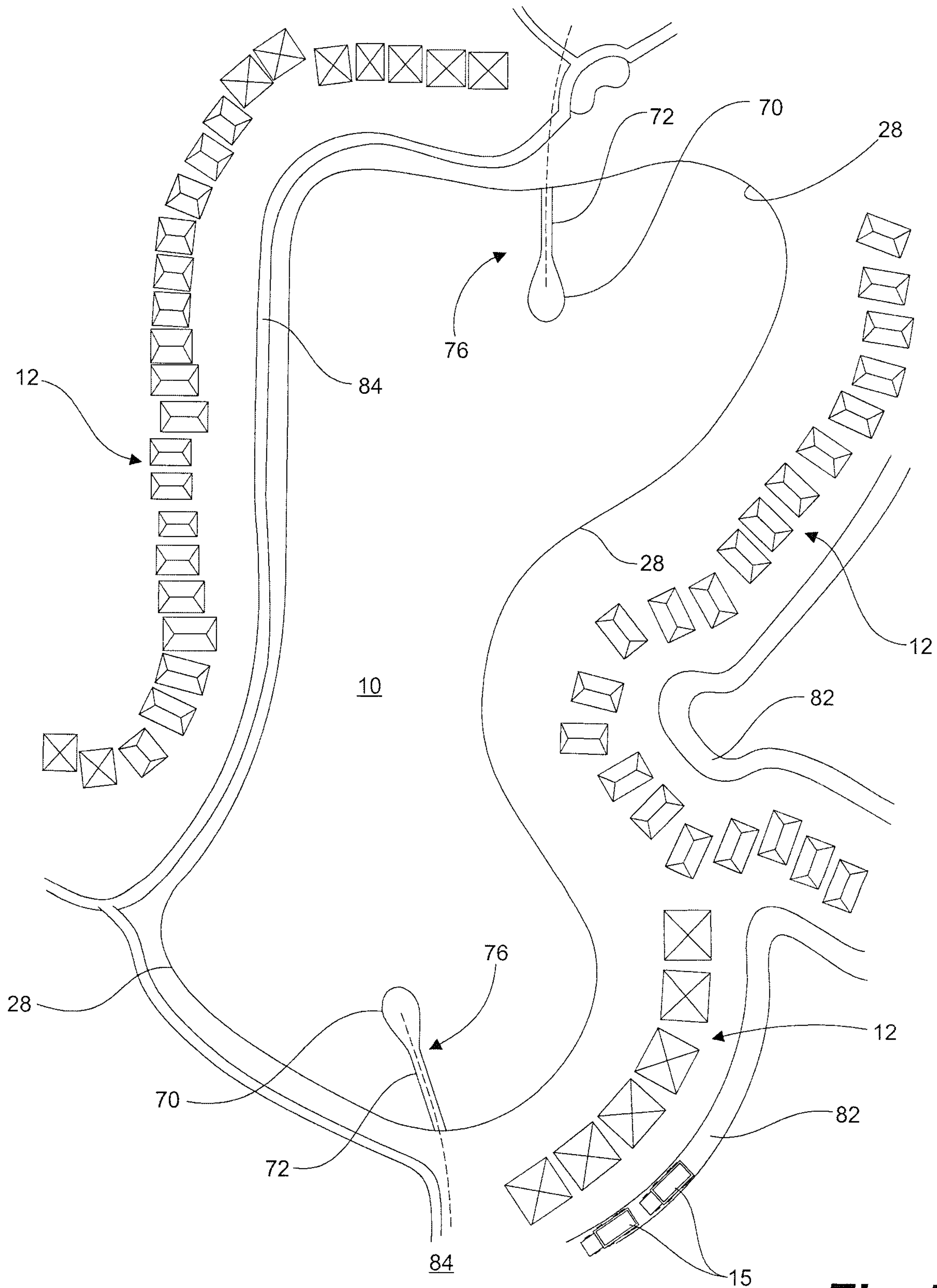


Fig. 5

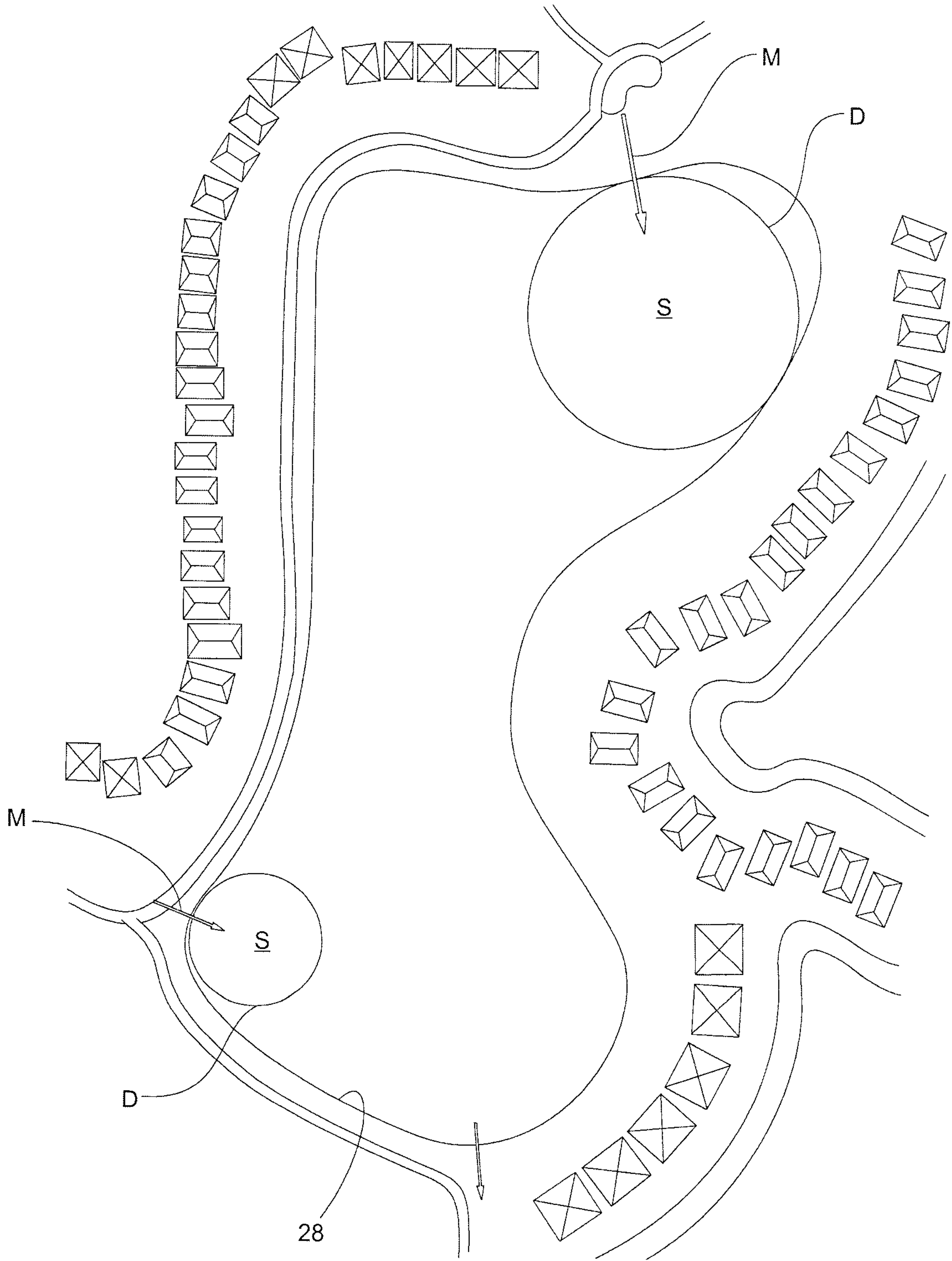


Fig. 6

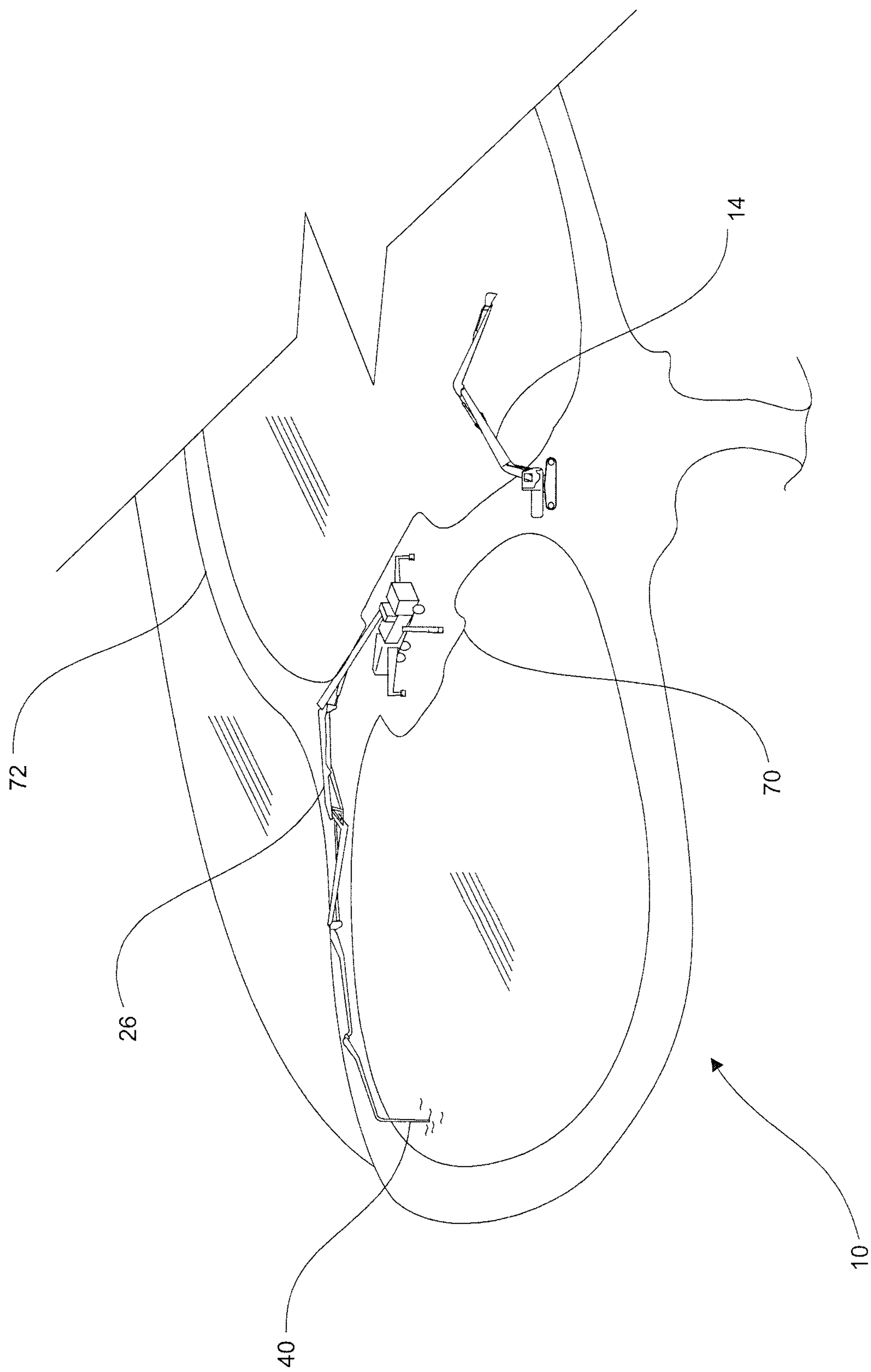


Fig. 7

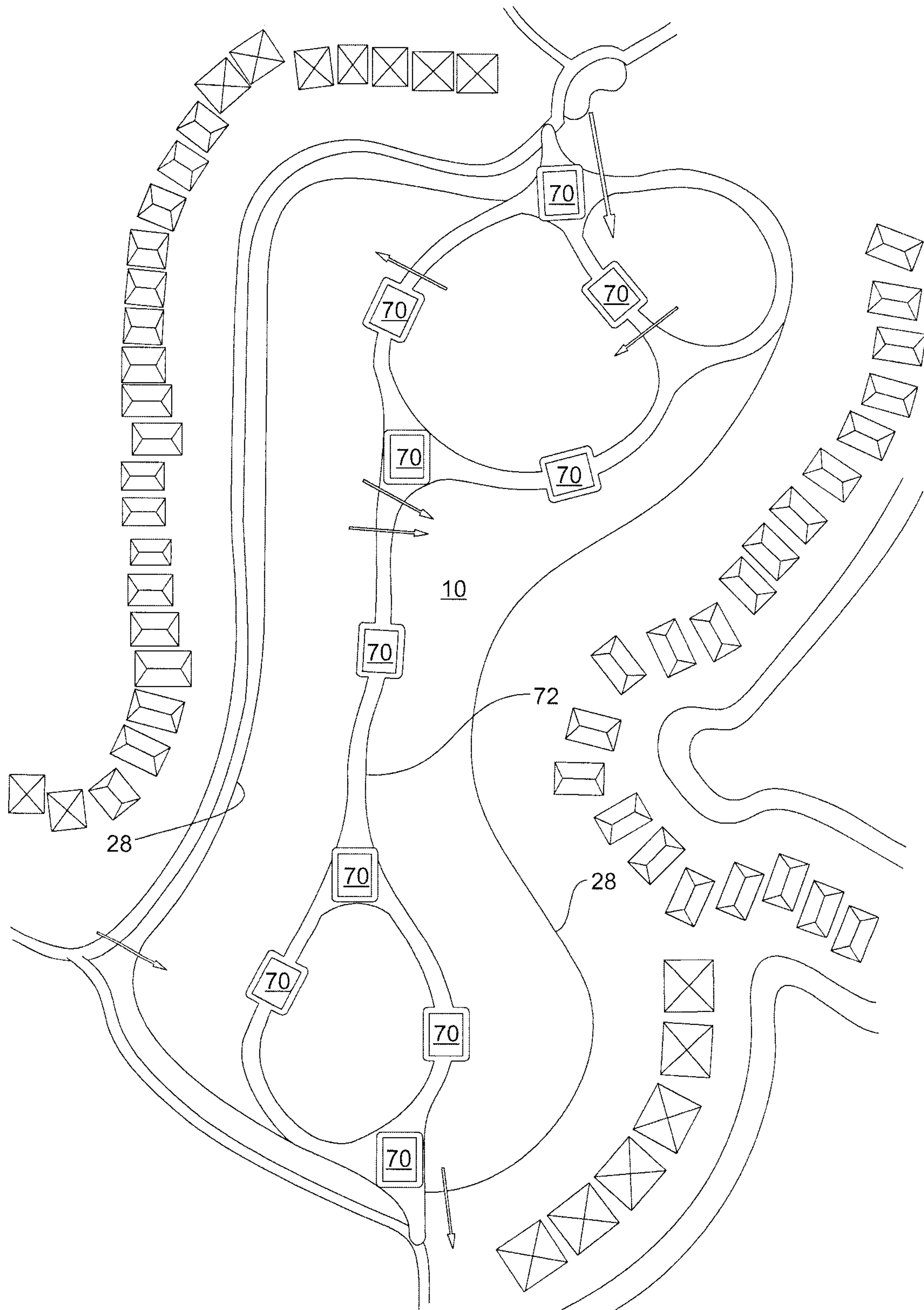


Fig. 8

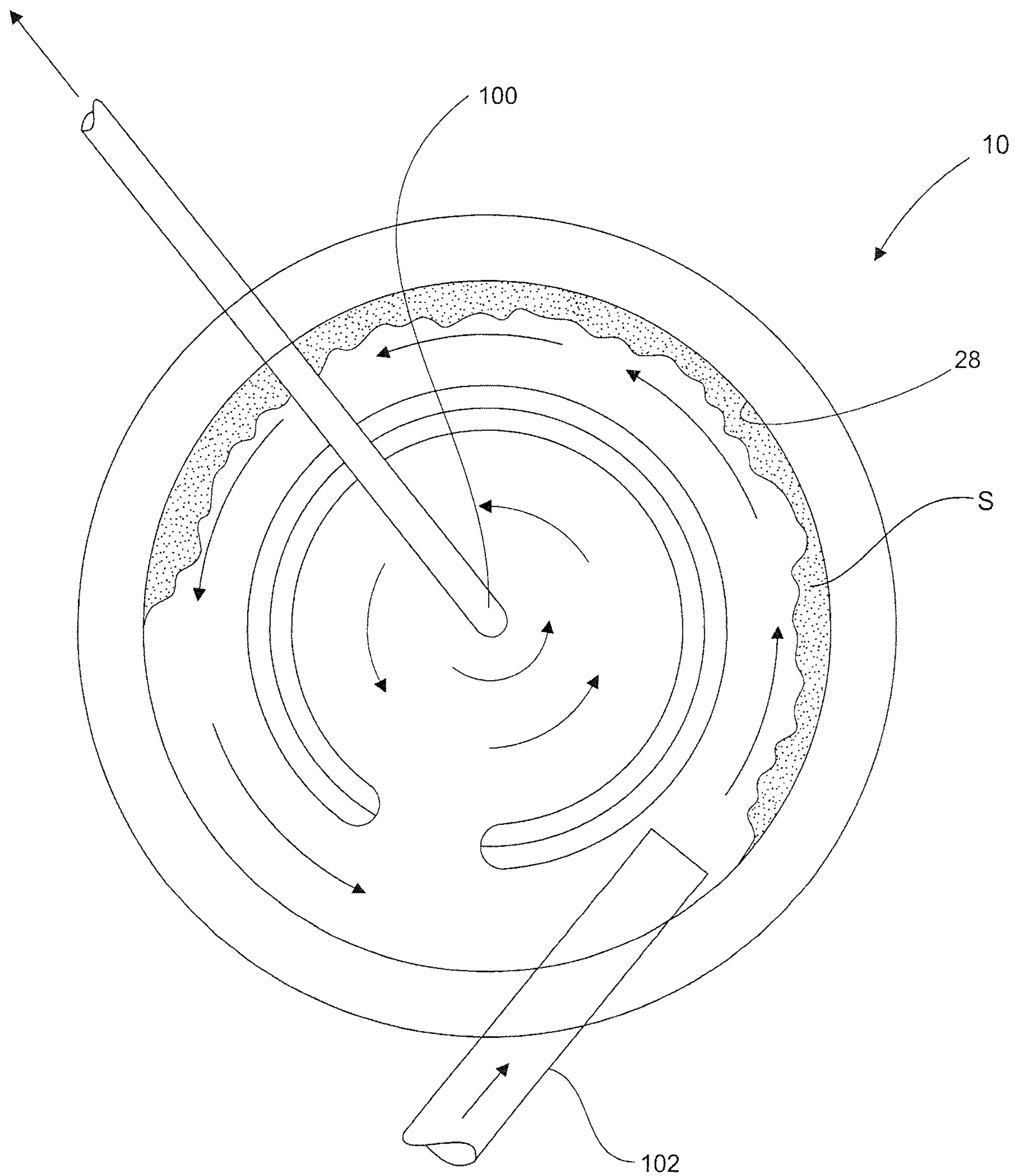


Fig. 9

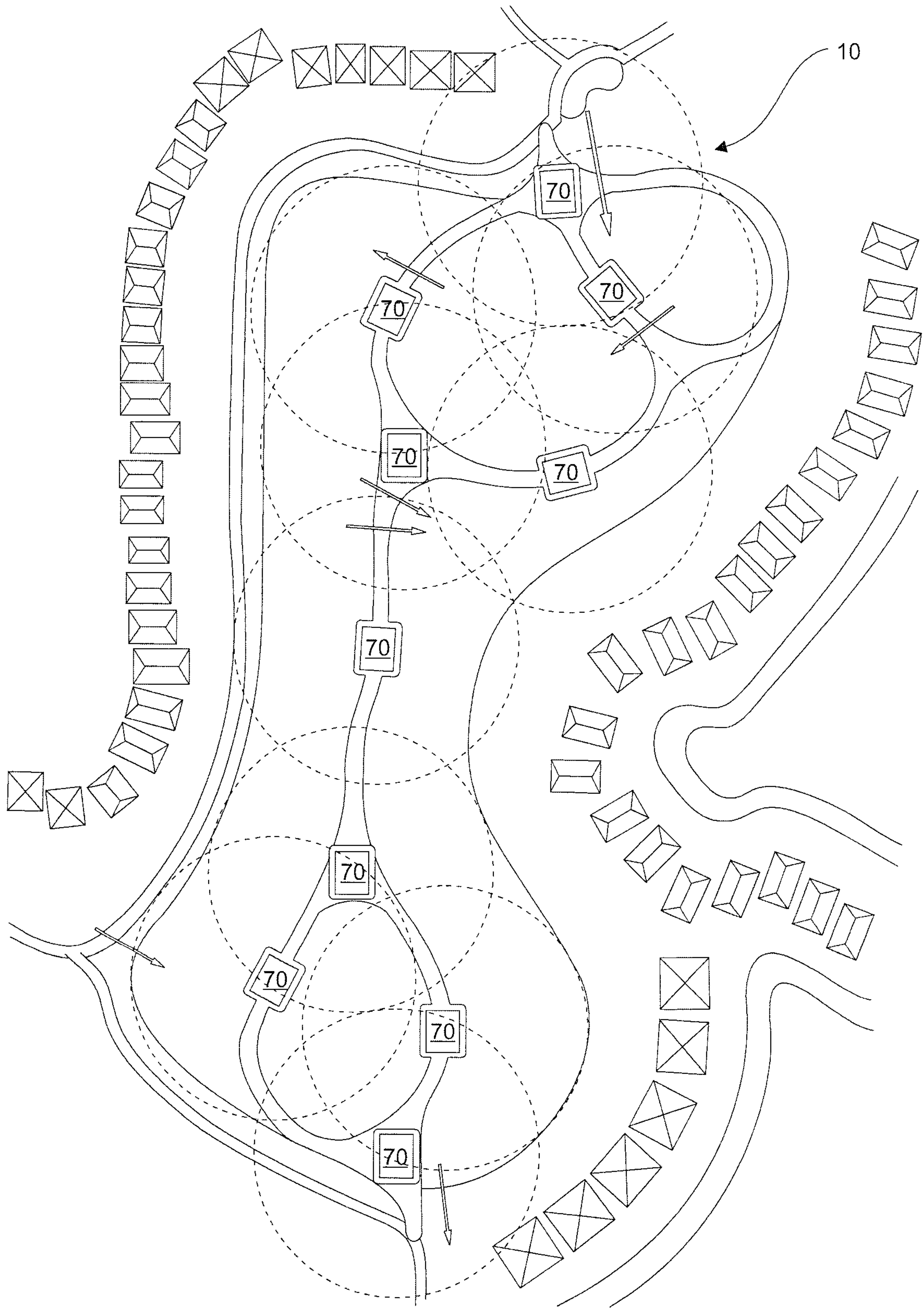


Fig. 10

